

US EPA RECORDS CENTER REGION 5



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Potential Health Hazard in the St. Louis Park  
Drinking Water

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## Origin and Chemical Composition of Creosote

1. Coal tar is a major by-product of the coking process that converts bituminous coal to coke by heat processing. Coal tar is a black viscous liquid comprised of thousands of compounds formed during the heating process and whose composition can vary according to the temperature and duration of heating. Higher temperatures and longer duration favors formation of polyaromatic hydrocarbons. Creosote is distilled from coal tar between 200 and 450 degrees centigrade leaving behind a solid residue called pitch. Creosote is a flammable, heavy, oily liquid that contains phenols, creosols, pyridine and numerous polyaromatic and heterocyclic compounds including strong carcinogens and mutagens. Polyaromatic compounds are multi-ring structures that contain only carbon and hydrogen, while heterocyclic compounds can have other elements in the ring in addition to carbon. Creosote heterocyclic usually have one nitrogen atom in one of the rings. Due to its caustic nature and oily base, it is most often used as a wood preservative and waterproofing agent.

2. Analysis of the water samples at the Reilly Tar Site clearly shows the presence of more than seventy-five creosote components, including dibenzanthracene, benzanthracene and benzo(a)pyrene, all of which have been proven to be carcinogenic and mutagenic in laboratory tests, and suspected from epidemiological studies to be implicated in human cancer (1,2).

3. The chemical composition of creosote is such that we

anticipate two distinct types of toxic effects, acute and chronic. Since creosote contains strongly acidic phenols, the most direct effect is marked dermal toxicity including localized reddening and swelling, burning, itching, pigmentation of the skin, blistering, ulceration, and gangrene. Eye injuries will include keratitis, conjunctivitis, and permanent corneal scarring. Industrial workers who routinely work with creosote report contact dermatitis. Exposure to sunlight worsens symptoms due to photosensitization. The National Institute of Occupational Safety and Health recommends coal tar workers wear protective clothing, masks, gloves, and goggles (3). However, the chronic toxicity problem from creosote is by far the greatest hazard due to the presence of carcinogenic and mutagenic chemicals.

#### Early Literature Identifying Creosote as a Carcinogen

4. Chemicals from creosote were some of the earliest known carcinogens in the environment. Sir Percival Pott in 1776 showed that chimney sweeps in England had a far higher incidence of skin cancer than chimney sweeps on the European continent (4). When he visited Flanders (Netherlands), he found the only difference in the two life styles was that chimney sweeps in Flanders routinely bathed, while British chimney sweeps bathed infrequently, if at all. He quickly made the association between soot and skin cancer which resulted in probably the first public health law, and the marked diminution of skin cancer in chimney sweeps.

5. The first real accomplishment in chemical carcinogenesis research occurred in 1915 when Yamagiwa and Ichikawa successfully

grew a tumor on the ear of a rabbit by painting coal tar extracts (5). This experiment was followed in 1930 by a British group led by Sir Ernest Kennaway who successfully isolated benzo(a)pyrene from coal tar and proved that this chemical was a potent carcinogen (6).

6. Creosote was suspected as a human hazard as early as 1924 by Cookson who produced skin tumors in mice with prolonged exposure to creosote (7). Cabot (1940) extended these findings with mixes of creosote and benzo(a)pyrene (8). Poel and Kammer (1957) showed both light and heavy creosote oils from high temperature coke-oven tars caused cancer in mouse skin. They also showed creosote oils without benzo(a)pyrene were carcinogenic in mice, proving there were additional uncharacterized carcinogens in creosote (9). These results were confirmed and extended by Boutwell and Bosch in 1958, who demonstrated tumor formation in mice after twenty weeks with twice weekly treatments of 25 microliters (1 drop) of undiluted creosote on the skin (10). Epidemiological studies of coke-oven workers and roofers who are continually exposed to these chemicals show a higher incidence of cancers of the digestive system, including the pancreas, and cancers of the buccal cavity and pharynx. Workers with only five years of coke-oven effluent exposure have increased risk of dying from lung cancer and kidney cancer (1). Roofers with twenty years exposure to coal tar fumes also showed elevated death rates from lung cancer and cancer of several other sites (2).

#### Mechanism of Chemical Carcinogenesis

7. During the course of the last few decades, chemical carcinogen researchers have extracted many other polyaromatic and

heterocyclic compounds from coal tar, and demonstrated their carcinogenic and mutagenic activity (11). There have been comparative studies in vivo in many species, tissues and cells on the relative carcinogenic activity of these compounds. These studies have been both to understand what's unique about these chemicals that enable them to cause cancer, and to determine if animals and humans will develop cancer from these chemicals by the same biological mechanisms. This of course would enable us to study animal models as a basis for understanding the genesis of human cancer. Extensive research for the past two decades has enabled several generalizations to evolve. One particularly important finding is the fact that environmental carcinogens are not tumorigenic until taken into the body and transformed into the cancer causing type by the tissues own biochemistry. It is now well established that the detoxification process in the tissues is a complex series of reactions that produce a number of biologically inactive derivatives for easy excretion from the body. During this process the carcinogen forms a very reactive intermediate that can interact with critical sites in the cell, usually thought to be DNA and initiate the cell into the biological progression toward malignancy (12,13).

#### Extrapolation From Animal Models to Human Carcinogenesis

8. The exact mechanism by which the cell responds to the chemical carcinogen and begins the cascade of events that turn a single initiated cell into a cancerous tumor remains obscure. However, the validity of extrapolating chemical carcinogenesis

studies in animals up to human susceptibility derives from a huge metabolic data base that has shown that carcinogens are metabolized by all animal species in an identical fashion as humans. Every animal and human tissue that has been studied uses identical biochemical pathways to change the carcinogen into inactive forms. In addition, many polyaromatic carcinogens form a whole series of metabolites with oxygen atoms placed at various locations on the molecule. It now appears that all animal species including human make the identical series of metabolites and the same type of interaction occurs between the carcinogen and the cellular DNA (14). Therefore, from the purview of the large body of empirical evidence, there are no qualitative differences between carcinogen metabolism in laboratory test animals and humans.

#### Initiation and Promotion

9. It is now well accepted that carcinogenesis is a complex series of steps in both animals and humans. In addition, we also know from epidemiological evidence (1,2) that human tumor development can have a long latency with many years before malignancy appears. This phenomenon is most likely the resultant of a series of events not mechanistically understood at the present time. The first step is termed "initiation" when the cell is confronted with the carcinogenic substance and is either directly transformed into a malignant cell or remains in a quiescent state until stimulated to undergo the process of uncontrolled growth and develop into cancer. This latter process which invokes stimulation of the initiated cell by other physical or chemical

agents, (e.g. radiation, trauma, PAH) is termed "promotion", and has been thoroughly documented in the literature (15).

10. Repeated doses of polyaromatic hydrocarbons to skin induces an abnormal multiplication of cells, and the appearance of cells that are not normally found in the skin. Studies in recent years have clearly shown that a number of polyaromatic non-carcinogens such as benzo(e)pyrene, and pyrene are promoters of skin tumorigenesis after initiation (16).

11. The difficulty in solving the mechanism of promotion is because of the long latency in humans (e.g. diseases derived from tobacco usage), and the effects upon cellular growth, function, and differentiation are markedly pleiotrophic, which means many cell types are affected. While many promoters are not carcinogenic themselves (e.g. pyrene, phenanthrene), they will significantly enhance the tumor forming potential of carcinogens, and stimulate tumor growth from subthreshold doses of potent carcinogens such as benzo(a)pyrene. The presence of promoting agents in the St. Louis Park water samples such as non-carcinogenic PAH would be expected to have marked promoting effects with chronic insult over many years. Also, there are definite chromatographic differences in the PAH molecules based on the number of aromatic rings. Benzo(a)pyrene is a five-ring structure and would tend to be less soluble in water and travel more slowly through the ground than smaller molecules with fewer rings such as naphthalene which has two rings, anthracene which has three rings, or pyrene which has four rings. Since the more potent carcinogens like benzo(a)pyrene are prevalent at the center of contamination (SLP Well 23), it might

be expected to reach the more distant wells some time in the future.

#### Inadequacy of Natural Defenses Against Chemical Carcinogens

12. Arguments have been raised by Reilly Tar to attempt to circumvent the fact that there exists a very real potential long-term hazard to the inhabitants in St. Louis Park. They attempt to ignore the problem, (ERT Report, Vol. I, page 12a) "Persons are exposed to a measurable burden of carcinogens in their daily diet and through other activities in normal everyday life. These scientists recognize that the human body has well-developed natural defense mechanisms that provide for effective detoxification of foreign chemicals, including carcinogens." If this statement is taken on face value, it is surprising that there is any human cancer incidence at all. However, a recent epidemiologic study places the problem in a more realistic perspective and completely negates this notion. It has been reported by the International Agency for Research on Cancer that "up to ninety percent of all cancer in the world is related to environmental influences" (17). This dire and impressive statistic attests to the imperfect barrier raised by our natural defenses, and requires that we constantly probe our daily environment to discover and remove carcinogenic hazards. It is important to realize that our incomplete knowledge of cancer causation, and which segment of the population is at greater risk, makes any accurate approximation of a minimum acceptable daily dose of carcinogen impossible. Adoption of a linear-no-threshold dose-response by the U.S. Government for chemical carcinogens is in my opinion a wise policy.



Our incomplete knowledge of carcinogenesis mechanism coupled with the large incidence of cancer in this country dictates a prudent and conservative approach to controlling those chemicals in our environment known to play a role in cancer causation. It may be that certain segments of our population have a greater susceptibility to cancer from carcinogenic chemicals. We know this with certainty in particular instances in the work-place, such as coal tar workers. However, there may be other environmental or genetic factors that predispose some people to possess a greater susceptibility than others. All individuals should be protected from what might be a dangerous exposure level of carcinogens until we have a better understanding of cancer causation. The most judicious approach to carcinogen and promoter removal from the drinking water should be applied.

13. Dr. Santodonato, the ERT representative stated during the public meeting in St. Louis Park on May 18, 1983, that promotion has only been demonstrated in mouse skin and not other species or tissues. This is not correct since there are additional promotion systems, such as rat liver (18, 19, 20), colon (21), pancreas (22), and bladder (23). Also, the statement was made, "it is possible to theoretically predict which PAH will be carcinogenic based on their molecular structure." This is also not correct since the current bay region hypothesis of chemical carcinogenesis is far from explaining the species differences in susceptibility as well as the PAH which do not follow the theoretical calculations (24). There are too many unknowns in the biochemical activation and detoxification pathway

to give theoretical hypotheses much weight, especially since it would imply that one would be able to predict potential danger, or lack thereof, from the St. Louis Park water.

14. In addition, the synergistic effect of carcinogen and non-carcinogen mixtures has been claimed by Reilly Tar to inhibit tumor formation (page 5, public meeting document). "... testing of well-characterized complex PAH mixtures has shown that synergistic effects do not occur, and in fact that the potency of carcinogenic PAH in complex mixtures can be inhibited by the presence of non-carcinogenic PAH." This statement implies that combinations of PAH such as found in creosote and the St. Louis Park water might show less tumor incidence than the individual carcinogens when tested separately. Since creosote is a complex mixture of carcinogens and non-carcinogens, and is carcinogenic (7 - 10), their statement cannot be correct. The published works used to support their claim are taken from Air Pollution and Cancer in Man (International Agency for Research on Cancer, Scientific Publication No. 16, and cited in the ERT report Appendix I, page I-14). One referenced paper by Pfeiffer (25), gave single injections of carcinogen mixtures and no further treatment for lifetime studies. Tumor incidence was measured at 114 weeks. This experiment does not represent the conditions at St. Louis Park. While tissues in the body have a natural amount of drug metabolizing enzymes, multiple chemical treatments and time (24 hours) are needed to induce formation of large amounts of activation enzymes. PAH from a single injection is cleared from the body

within 24 hours, It is therefore reasonable to assume that the available activating enzyme will be diluted between the mixture of carcinogenic and non-carcinogenic PAH. This in effect will reduce the amount of enzyme that can activate the carcinogenic components in the mixture and result in less critical hits on the target sites in the cells. With no further treatment one should expect fewer tumors at the end of the experiment, and this is what that research paper reports. Correlating these results to the situation in St. Louis Park is a non-sequitur where the population is exposed to constant chronic doses of carcinogens and promoters and not to a single dose, as in the reported experiment. Unlike the mice in the Pfeiffer experiment, the people drinking the contaminated water will most likely have their drug metabolizing enzymes in a constantly elevated state.

15. The second publication utilized by the ERT report to support their argument for the lack of effect of mixtures is by Schmahl, et al (26). These investigators applied mixtures of carcinogens and non-carcinogens twice weekly to mouse skin for their entire lifetime. This experiment is certainly more comparable to the situation at St. Louis Park. The ERT report states (page I-14) "These investigators found no effect on tumor incidence that could be attributed to the presence of non-carcinogenic PAH in the mixture." This is a somewhat surprising evaluation of the results in this paper since the data would appear to contradict this conclusion and strongly supports the case for control of the non-carcinogenic PAH. To quote from the summary of the Schmahl paper (page 58), "It was not possible to demonstrate

an inhibitory action of most of the weak-to-inactive hydrocarbons; on the contrary, an additive effect of the two types could be observed. At very high doses (almost 10 times higher than the highest doses selected in the rest of the trial) the group of substances which were supposed to be non-carcinogenic also proved to be biologically active." It is apparent from many such studies that large amounts of non-carcinogenic PAH in the drinking water may pose a significant hazard for potentiation of carcinogenesis.

16. It should also be mentioned that the Water Quality Criterion Document For Polynuclear Aromatic Hydrocarbons (January, 1979) was written for EPA by one of the authors of the ERT document (Dr. Santodonato), and demonstrates awareness of the promoter problem in drinking water. ERT Report, Appendix I, page 79, quotes "The second stage, promotion, is a prolonged process which does not require the presence of a carcinogen, but nevertheless a chemical stimulus must be supplied ... The formation of skin tumors by polycyclic hydrocarbons may also be influenced by inhibitors and accelerators (co-carcinogens) thus complicating the interpretation of experimental data." On page 130, the report refers to the paper by Thompson and Slaga, *Journal of Investigative Dermatology*, 66: 108-111, 1976 and quoted "These results may be interpreted to indicate that a chemical carcinogen may not necessarily induce its own bioactivation, but instead can be transformed into a reactive intermediate by virtue of increased AHH (carcinogen activating system) activity stimulated by other non-

carcinogenic compounds." Although the danger of exposure to complex mixtures is barely mentioned in the ERT Report, references to previous works in the literature by the authors clearly show they are aware of the dangers from promoters and initiators and are cognizant of the potential hazard posed by exposure to complex mixtures of carcinogens and non-carcinogens.

#### Conclusion

17. We have a situation where we can present an argument from historical prospective and from the current literature that unequivocally implicates this complex mixture of compounds (creosote) in cancer causation and potentiation. Of utmost concern are the instances where the exposure will be of the longest duration, such as young children who will live a major portion of their lives within the contaminated zone. It has been shown that cancer incidence by benzo(a)pyrene treatment increases with duration of exposure and is independent of age (27). In addition, to the known carcinogens that have been isolated and characterized, there are literally hundreds of other chemicals present in creosote that are of unknown hazard since testing is relatively expensive and the assays have simply not been done. Also, the literature has very limited information on the effect of mixtures, and it seems self-evident that the St. Louis Park population will be exposed to small amounts of known carcinogens (assuming the charcoal filtering plants are functioning) and relatively large amounts of compounds that are known or suspected tumor promoters (if greater than 200 nanograms per liter of non-carcinogens).

18. In effect, we could have a rather large initiation/promotion

experiment ongoing with the populace of the St. Louis Park area as test subjects. Since analysis of the various SLP Wells show there is a chromatographic effect from the most contaminated area at the center (Well 23) to the least contaminated area at the furthestmost site away from the direction of flow, we could possibly predict (assuming the population sample is large enough, and is stable) concomitant distribution of cancer or mutation or other maladies (e.g. spontaneous abortion), with distance from the source.

19. In my opinion, it is prudent to take a most conservative approach to the problem and do the utmost to restrict the level of exposure of the people in the St. Louis Park area to no more carcinogenic and promoter chemicals than a control population in a similar environment.

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REILLY TAR AND CHEMICAL CORPORATION  
REFINING AND WOOD-PRESERVING OPERATION AT  
ST. LOUIS PARK, MINNESOTA

by  
Warren S. Thompson

Introduction

Many facets of the operation of coal-tar refining and wood preserving plants use identical processing procedures. Unique aspects of the operation of a specific plant can be ascertained only by observing the operation or, as in the case of the Reilly Tar and Chemical Corporation (RTC) facility at St. Louis Park, by obtaining information from former employees and plant documents. The description of operating procedures prepared from these latter sources of information is very similar to procedures known to have been used by similar coal-tar refining and wood preserving plants during the period in question.

The purpose of this report is to describe various aspects of plant operations. Sources of information on which the report is based include RTC documents, the ERT report, RTC answers to interrogatories and depositions of RT employees, along with publications prepared by the author individually or as a member of a team.

## Wood Preservation Process

### Conditioning

Round wood products must be debarked and conditioned before preservative treatment. Conditioning of both round or sawn wood may be accomplished by air seasoning or kiln drying. Alternatively, the moisture content of wood may be reduced sufficiently to permit preservative treatment with certain types of preservatives by either steaming the wood in the retort, heating it in oil under reduced pressure, or by exposing it to hot vapors of organic solvents in a process called vapor drying. Preservative treatment of difficult-to-treat species may be expedited by incising, a process in which the wood is pierced by knives to provide avenues for penetration of the preservative solution.

### Treatment Process

Pressure treatments involve the application of pneumatic or hydrostatic pressure to wood in a vessel designed for that purpose to expedite movement of the preservative liquid into wood. These processes account for fully 95 percent of all wood treated.<sup>1/</sup>

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<sup>1/</sup>The remaining 5 percent is treated by non-pressure processes which are carried out at atmospheric pressures. These processes include thermal, brush, dip and spray, diffusion, vacuum and cold-soak methods.

In the normal application of preservative treatments by pressure processes, wood loaded on trams is introduced into the pressure retort and, after appropriate conditioning, may be subjected to either one of two treatment schedules: full cell or empty cell (see Appendix A). Pressure processes were used for wood treated at the RTC plant at St. Louis Park.

Differences in the amount of preservative injected into wood are determined by the biological hazard to which the wood will be subjected in service. Products such as marine piling are treated to retentions of up to 20 pounds per cubic foot by the full-cell process. Poles, crossties, fence posts, and other products for land and other non-marine uses are treated by the empty-cell process, for which retentions of from 6 to 12 pounds per cubic foot are typical.

#### Preservatives

Three major preservatives are used by the wood preserving industry: creosote, pentachlorophenol, and an inorganic salt formulation the active ingredients of which are copper, chromium, and arsenic. The last named preservative was not used by RTC at St. Louis Park and, therefore, is omitted from the discussion which follows.

Creosote may be applied to wood in undiluted form or diluted with coal tar or petroleum. Pentachlorophenol

is applied in a solvent of low volatility or in such volatile solvents as mineral spirits, methylene chloride, or liquified petroleum gas. When a solvent of low volatility is used, which was the case at the St. Louis Park facility, the solvent is left in the wood at the conclusion of the treating cycle. Conversely, when certain volatile solvents are used, the solvents are recovered from the wood for reuse at the end of the treating cycle.

Other preservatives, primarily water-soluble salts of zinc, mercury and copper, have been used by the wood treating industry in the past. Among preservatives of this type zinc chloride is important because of its early use by the wood preserving industry to treat crossties. This chemical was used at the St. Louis Park facility of RTC for approximately 10 years, from about 1920 to 1930. The use of zinc chloride as a wood preservative was discontinued in the late 1930's or early 1940's because of its high solubility and the resulting ease with which it could be leached from treated wood.

#### Refinery Operation

Typically, crude tar is pumped from a storage tank through a series of heat exchangers where it is preheated. The heated tar flows into a still and is separated by

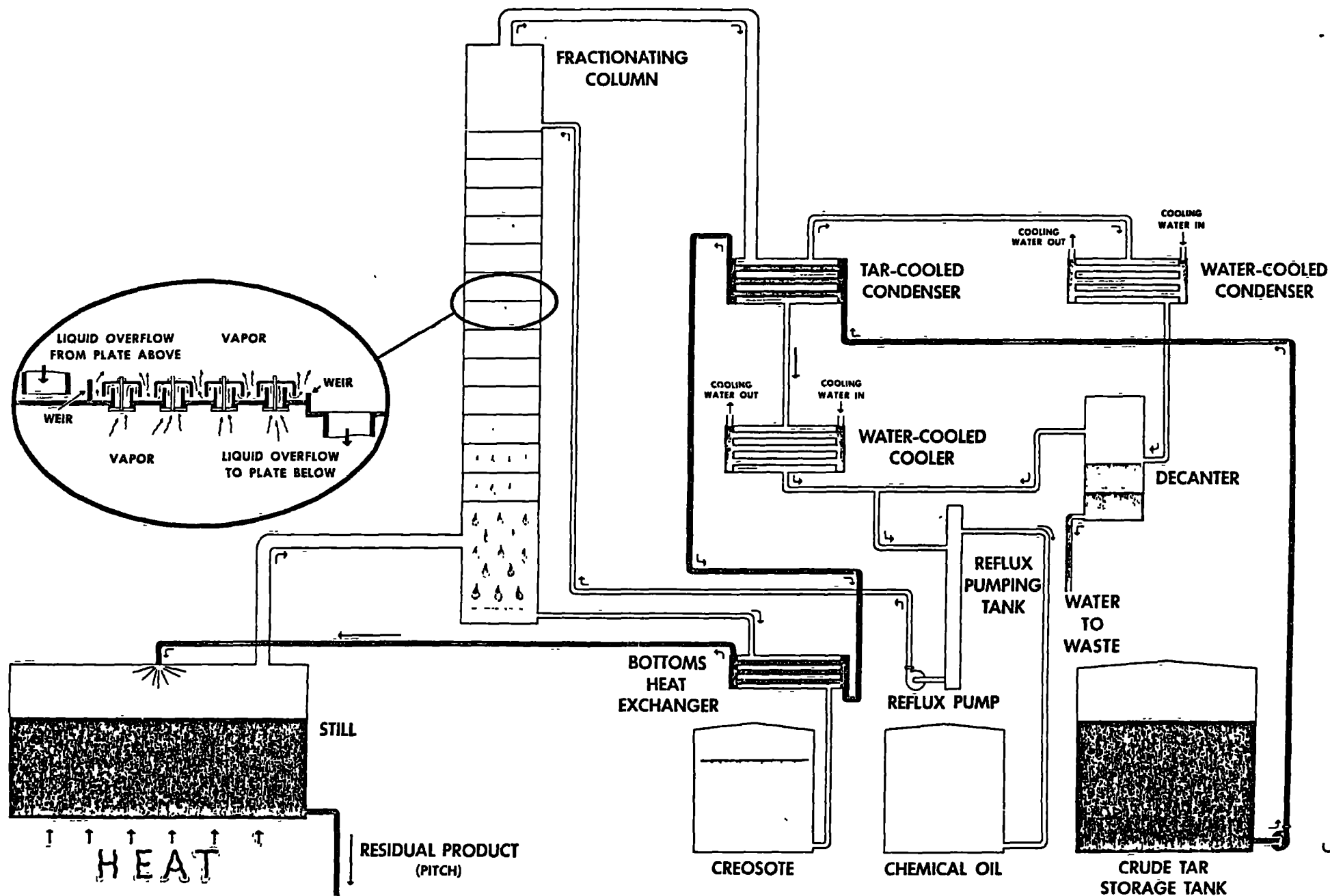


Figure 1. Elements of tar distillation. (Adapted from Anonymous. 1949. Where tar comes from. Koppers Co., Inc., Pittsburgh.)

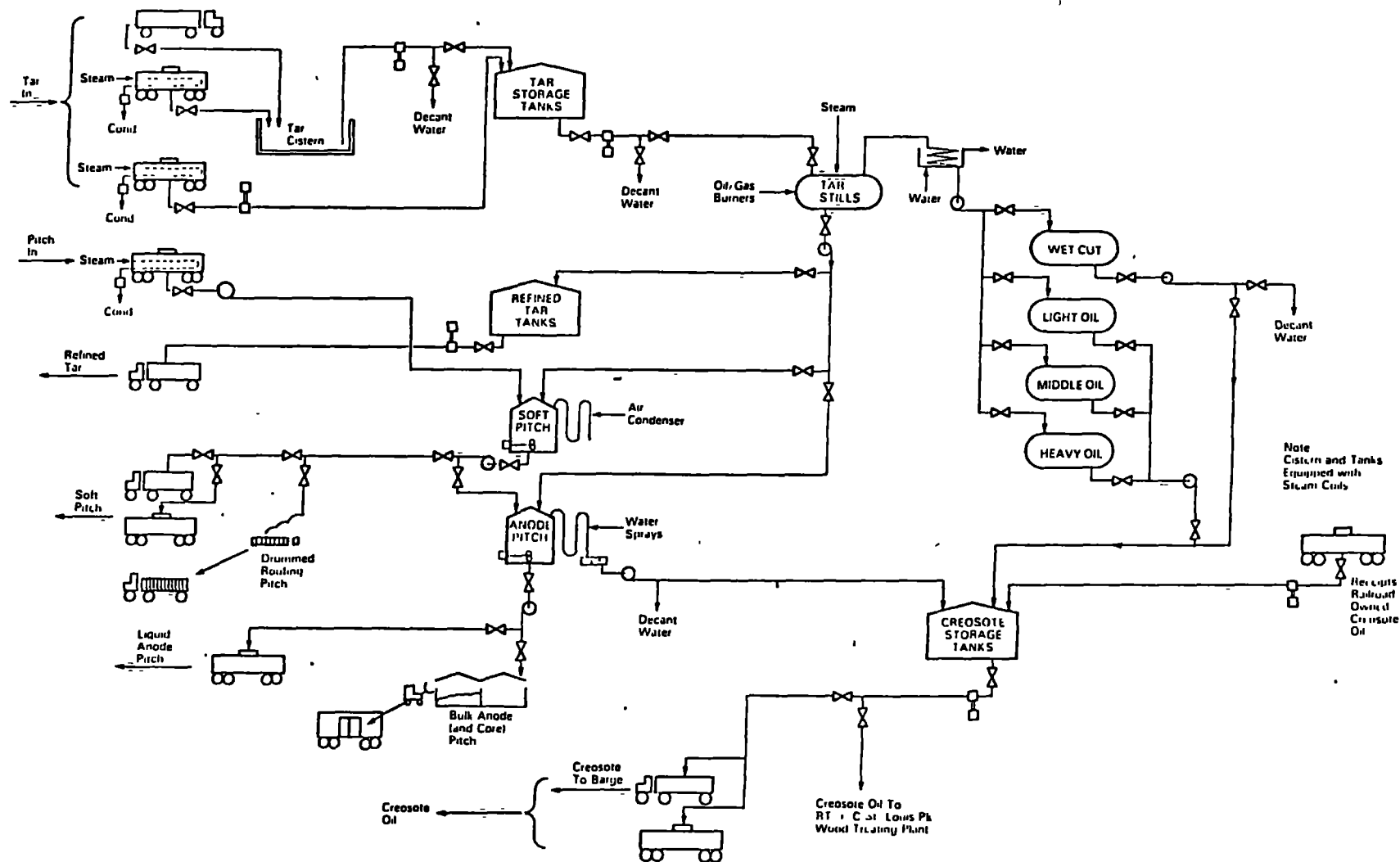


Figure 2. Elements of coal tar refining operation. (Adapted from ERT report, Vol. II.)

distillation into its two major components--pitch and oil. The still itself can be a simple tank over a fire (Figure 1), or it may be constructed like a fire tube or a water tube boiler. Stills can be designed to operate continuously or in a batch mode.

The crude tar is heated during distillation to remove successively higher boiling fractions. The initial distillate (the wet cut) is composed of a high proportion of water, which is rich in phenols and hence a potential source of pollution. The wet cut is followed by the lighter oils and those, in turn, by the heavier oils, as the temperature in the still increases. The fraction of tar remaining in the still at the completion of the distillation process is pitch. The rate at which the crude tar is heated in the still is regulated to produce a pitch with the desired properties. Hard pitch can be produced by distilling off all of the oils. Pitch of various degrees of softness can be produced by regulating the amount of residual oil retained in the still.

Vapors flow out of the still to the fractionating column where they are separated into several fractions: chemical oil, top-of-column oil, uncorrected creosote oil, and heavy oil.

Figure 2 is a simple schematic of the distillation process at St. Louis Park.

Creosote was one of the main products produced by the tar distillation plant at St. Louis Park. Creosote is a blend of various distillation fractions designed to impart specific physical characteristics that meet standard set by the American Wood Preservers' Association (AWPA). Appendix B describes the physical properties and chemical makeup of creosote.



### Sources of Pollution

Pollution associated with coal-tar distillation plants and wood-preserving plants that use creosote are primarily phenolics, which are part of the acid fraction of coal-tar distillates, and polynuclear aromatic hydrocarbons (PAH) that make up the neutral fraction. Among the traditional wastewater parameters--oil and grease, total phenols, and oxygen demand--oil and grease is probably the most important at plants using creosote because in wastewater the PAH's are associated with the oil phase.

Wastewater characteristics vary with the particular preservative used, the volume of stock that is conditioned prior to treatment, the conditioning method used, and the extent to which effluents from the retort are diluted with water from other sources.

### Effect of Preservatives Used

Typically, wastewaters from creosote and pentachlorophenol treatments have high phenolic and oil contents, high chemical oxygen demand (COD) and may have a turbid appearance that results from emulsified oils. These wastewaters are always acidic in reaction, the pH values usually falling within the range of 4.1 to 6.0. The high oxygen demand of wood-preserving wastewaters, that is, the oxygen consumed during the biological or chemical oxidation

of the organic materials in the wastewater, is caused by entrained oils and by wood extractives, principally simple sugars, that are removed from wood during the conditioning process.<sup>2/</sup>

Many plants use the same preservative and follow the same basic treating practices. Therefore, the wastewaters that they generate are qualitatively similar with respect to most chemical and biochemical properties. Quantitatively, however, they differ widely from plant to plant, and even from month to month at the same plant.

#### Effect of Conditioning and Rainwater

Among the several factors influencing both the concentration of pollutants and volume of effluent, total conditioning time, whether by steaming or Boultonizing,<sup>3/</sup> is the most important. Conditioning reduces the moisture content of the wood and improves its treating characteristics. Water from conditioning accounts for a significant fraction of the total pollutant loading in a plant's effluent, since it contains preservative from the retort

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<sup>2/</sup>Wastewaters from wood-preserving operations may also contain traces of copper, chromium, arsenic, zinc, and boron, depending upon the specific preservatives and/or fire-retardant formulations used.

<sup>3/</sup>Boultonizing is a wood conditioning process in which wood is heated under vacuum in oil. After conditioning, the wood is treated in the usual manner using a standard pressure process.

and sugars and other organic materials extracted from the wood during the conditioning process. Conditioning is also an important factor in determining the total volume of wastewater that must be processed.

Rainwater that falls on or in the immediate vicinity of the retorts and storage tank farm--an area of about one acre for the average plant--is also important in determining total wastewater volume. Contaminated rainwater presents a treatment and disposal problem at most plants, but can be especially troublesome for plants in areas of high rainfall. For example, a plant located in an area that receives 30 inches of rain annually must be equipped to process 0.7 million gallons of contaminated water from this source. Rain water that falls on treated and untreated products storage areas and on other areas removed from the processing facility becomes contaminated if permitted to flow across the area occupied by the processing facility. This water is usually diverted away from the processing facility by a system of drainage ditches installed for that purpose.

Wastewater volumes for representative plants using different methods of conditioning are shown in Table 1. Both total volume and volume per cubic foot of production are given. The differences among conditioning methods in volume of wastewater is apparent. For a plant producing

Table 1. Comparison of the volume of process wastewater generated by four conditioning methods.

<u>Cond. Method</u>	<u>No. of Plants</u>	<u>Avg. vol. wastewater (gpd)</u>	<u>Gal/ft.<sup>3</sup></u>	<u>Range gal/ft.<sup>3</sup></u>
Boulton	14	5,600	1.03	0.39-3.26
Open Steaming	14	9,250	1.87	0.55-9.01
Closed Steaming	8	1,370	0.45	0.17-0.97
Air-Kiln Drying	11	3,500	0.91	0.15-5.26

50,000 ft.<sup>3</sup> per week, a minimum discharge of 50,000 gal. per week (7,000 to 10,000 gpd) would be expected. The actual discharge prior to the early 1970's for the same plants was probably greater than this value, which is based on plants operating during the period of 1975 to 1979.

#### Other Sources of Wastewater

In addition to rain water and wastewater originating in the retort during the conditioning process, other sources contribute to the total volume of effluent discharged from a plant. These include barometric condenser cooling water, cooling water from vacuum pumps and heating coil condensate. The volume of wastewater originating from these sources varies widely from plant to plant and from time to time at the same plant, depending upon the method of conditioning that is used, the number of retorts, and whether or not the condenser cooling water is recycled or discharged after a single use. The volume of cooling water generated can total 30,000 gallons per day or more at large plants that use a single-pass system. Most plants recycle their cooling water to a lagoon, a practice used at the RTC plant in St. Louis Park.

Wastewater from the various sources within a plant may be contaminated or noncontaminated when discharged depending upon its use in the process. Ordinarily, cooling water used in tube-type condensers, heating coil condensate,

and rain water that does not fall directly on the area occupied by the processing equipment or treated product storage areas is not contaminated and can be discharged without treatment. Barometric condenser cooling water, cooling water used with certain types of vacuum pumps, and wastewater from the retorts must be treated prior to discharge. Rain water may or may not become contaminated depending upon where it falls on the plant site.

The importance of coil condensate as a source of pollution varies with the attention given maintenance at a plant. Contamination can occur only if coils develop leaks through which chemicals can enter. Many plants today routinely recycle coil condensate for boiler make-up water. This practice is not possible if the coils are not well maintained, as appears to have been the case at the RTC facility at St. Louis Park.

While the characteristics and volume of process wastewater discharged by a plant have a significant influence on soil and water pollution downstream, it is improbable that the pollutant concentrations in the soil at various locations on the Reilly Tar plant site and downstream from it can be accounted for by wastewater flow alone. Major spills, perhaps in combination with the discharge of wastewater without oil separation or with inadequate separation would be required to account for the high soil loadings reported in the ERT report. Spills are mentioned in several RTC documents reviewed

during the preparation of this report. These spills were associated with the operation of both the treating plant and the tar distillation plant.

#### Sources of Pollution at St. Louis Park

Estimates of process wastewater and total wastewater flow and pollutant loadings at the RTC St. Louis Park facility are presented here. Estimates are based on data contained in RTC documents, information obtained from transcripts of depositions of RTC employees or former employees and from the ERT report. In cases where data were not available to permit a careful calculation of wastewater flows, estimates were made based on the experience of the writer..

Assumptions made in calculating annual discharge from the facility are presented by source of wastewater. Sources of data and the rationale for the assumption on which discharge volumes are based are also presented whenever appropriate. A work year of 300 days was assumed for those production units for which it was necessary to convert daily discharge rates to an annual basis. Some items of equipment, boilers for example, operated on a different schedule from that of the plant as a whole and the appropriate operating schedule was used in calculating flow volumes. Volumes for each source are discussed individually then summarized in tabular form. Only those

sources of wastewater generated by plant processes, operations necessary to plant processes, and storm water runoff are reviewed in this document. Losses of product resulting from plumbing leaks, spills, and explosions are not covered.

Sources and volumes of wastewater are summarized below by type, either process or non-process. Process wastewater is defined by EPA as water that has been in contact with the products of the process or the chemicals used therein, and will include, for example, cylinder condensate. Non-process wastewater is water, such as coil condensate, that has not become polluted.

#### Cooling Water

Cooling water was used for air compressors and for condensers in the refinery. Cooling water for the compressor used in the wood preserving operation to supply compressed air to the retort is presumed to have been pumped from the cooling pond adjacent to the refinery building and used on a single-pass basis. Discharge volume would vary with the number of charges treated annually and the duration of the pressure cycles. If it is assumed that the volume treated per charge was 60 percent of the void volume of the retort (4,807 ft.<sup>3</sup>), or about 2,900 ft.<sup>3</sup>, the number of charges treated annually would be approximately 862. If it is further assumed



that the compressor operated three hours per charge and that two charges were treated simultaneously one-third of the time, the total hours of operation associated with wood preserving would be:

$$862 \times 0.67 \times 3 \text{ hrs.} = 1733 \text{ hrs/yr.}$$

A flow rate of 20 gallons per minute would generate 2,080,000 gals/yr gross discharge, or about 1,678,000 net if one assumes a 15 percent evaporation.

Compressors were also used to supply air for the airlift pump on the Republic deep well (well 23) to pressurize tank cars for unloading purposes, and to supply shop and process air in all parts of the Reilly plant complex. These compressors were located in the vicinity of the refinery. There were at least two compressors used for this purpose--35 and 50 HP units--and both were water cooled. It is unclear whether one of these units was also the unit used in the wood preserving operation. If this is the case, that unit undoubtedly operated considerably more than the 1733 hrs/yr required to meet the needs of the wood preserving operation. One of the compressors operated 6 hrs/day to supply the airlift. If it is assumed that both units operated 5 hrs/day and that the cooling water was turned off when they were not operating, the annual combined gross usage of cooling water would be approximately 7,200,000 gallons for a flow rate of 20 gals/min per unit in a 300-day work year. This volume would be

reduced to 6,120,000 when evaporation losses of 15 percent are accounted for. It seems probable that the cooling water for the 35 HP unit, which was located near the cooling pond in the pump house, was recycled. Therefore a net usage of cooling water of 3,060,000 gallons per year was used in computing the contribution of this wastewater source to the total discharge from the plant.

#### Steam Condensate and Boiler Blowdown

Process steam for both tar distillation and wood preserving was usually provided by a Riley-Badenhausen water-tube boiler with a capacity of 20,000 lbs/hr. A Williams Bros. fire-tube boiler with a capacity of 10,000 lbs/hr was used as a standby, and as a backup for the larger boiler when steam demand exceeded 20,000 lbs/hr. On occasion the demand for steam exceeded the combined capacities of the two boilers. The boilers were not turned off during cold weather but were turned off on weekends during the summer unless the plant was operating on a 7-day schedule.

Steam usage would have been greatest in the winter because of the demand created by uninsulated retorts and steam lines. Steam loss from the latter source is referred to in several RTC memoranda, but is dramatized in Mr. T. E. Reilly's memorandum of October 7, 1958, to Mr. Holstrom. Mr. Reilly stated that the steam loss in uninsulated

pipes in pipe trenches was 600 pounds per hour during dry weather but increased to 12,000 pounds per hour when the steam lines were immersed in water. In calculating the cost of this steam loss, Mr. Reilly assumed that the steam lines were immersed 10 percent of the time. Other Reilly documents state that the trenches were filled with water four months per year.

Calculation of volume of steam condensate was based on an average steam demand of 15,000 pounds per hour, 16 hours per day, 300 days per year. Actual demand exceeded 30,000 pounds per hour for a period of the work day during cold weather and probably less than 15,000 pounds per hour during part of the day during the spring and summer months. Since none of the condensate was recycled, the gross volume of water entering the drainage system from this source was 8,676,700 gallons per year. The net discharge, assuming an evaporation rate of 25 percent, would have been approximately 6,506,000 gallons.

Boiler blowdown, the periodic release of water from a boiler to prevent build up of solids, was another source of wastewater at the plant. The volume of boiler blowdown is conservatively estimated to have been 2,500 gallons per day, or about 750,000 gallons per year. The net annual discharge from this source after correcting for a 25 percent loss by evaporation is estimated to have been 562,500 gallons.

### Stormwater

The only other source of water that contributed to the total discharge from the plant was stormwater that fell on the 77 acres that comprised the plant property. Annual stormwater run off is estimated to have been:

$27,225 \text{ gal/acre-in.} \times 77 \text{ acres} \times 27 \text{ in.} \times 0.5 = 28,300,000$  gallons. This calculation assumes a run-off factor of 0.5. Because run-off is a function both of severity and duration of rain storms, season, and soil type, the run-off factor at the plant could have ranged from 0.5 to 0.7. The lower end of this range was used because of references in Mr. Horner's deposition to sand and gravel in the soil which would promote rapid absorption of rain water into the soil.

### Refinery Operation

The discharge of process wastewater from the refinery was apparently quite small and was further reduced when the by-products operation was discontinued. Process wastewater discharge associated with refinery and by-products operations was reported to be about 244,000 gallons annually in 1940 and came from the following sources:

Sodium sulfate solution	182,000 gallons
Tar distillation (wet cut)	62,000 gallons

Water from tar distillation, that is the wet cut, is the water that occurs naturally in crude coal tar in an amount equivalent to about one or two percent by weight of the coal tar and is recovered during the early stages of tar distillation.

Based on documents obtained from RTC, the volume of wet cut ranged from about 2,011 to 6,500 gallons per week and averaged 4,500 gallons per week over the life of the plant, or about 234,000 gallons per year. Further, Mr. Leshar stated in his deposition that three 3,500-gallon batches of sulfate water were generated weekly during the period that the by-products facility was operating. This source would thus contribute about 546,000 gallons to annual plant discharge for those years.

Another source of contaminated water in the refinery was quenching water used to cool molten tar and coke. Tar-quenching water amounted to only a few gallons per minute (over a period of 1 to 2 hours) because of the high evaporation rate. Water was used to quench coke prior to 1955 when the production of coke was curtailed. Water from this source was vaporized in the stills, condensed, collected and discharged. The average contribution of quenching water from both sources to total plant flow is

estimated to have been 1,440,000 gallons per year over the life of the plant. This volume is based on a flow of 10 gallons per minute over a period of 2 hours for 300 days annually in the case of pitch quenching, and 300 gallons per still per day, 300 days per year, for 12 stills for coke quenching. The actual volume of discharge from these sources may have differed from this estimate by up to 50 percent.

A scrubber, which was installed and operated for approximately two years before the plant closed to reduce odors from the refinery operation, discharged about 100 gallons per day. This source was ignored in computing the total plant discharge.

Cooling water was probably the largest volume of wastewater discharged from the refinery operation. It was used to cool the condensers through which products of the distillation process passed. Each still was equipped with a box condenser that received water either from the cooling pond or by direct connection to the water supply from the plant's deep well. Cooling water was ordinarily recycled to the cooling pond; but whenever the temperature in the pond increased to the point that the efficiency of the condensers was affected, the water was used on a single-pass basis. That is, it was discharged after one pass through the condensers.

Flow rate to each box condenser was estimated to be 30 to 100 gallons per day. For a flow rate of 50 gpm, the gross annual usage of cooling water for four stills would total 57.6 million gallons if the stills operated 16 hours per day, 300 days per year. (Gross consumption of cooling water would have been much greater prior to 1961 when from 8 to 17 stills were in operation at the plant.) Net discharge of cooling water from the refinery can only be estimated because the frequency and duration of use of single-pass cooling water is unknown. If it is assumed that a single-pass system was used 5 percent of the time--that is, the equivalent of about 15 work days per year--the volume of discharge would have totaled 2,400,000 gallons after correcting for evaporation.

#### Wood Preserving Operation

Annual production of treated wood products at Reilly's St. Louis Park plant ranged between 1.8 and 3.2 million cubic feet. An average production of 2.5 million cubic feet per year was used in calculating the estimated discharge volume. This volume was assumed to be distributed among products as shown below:

Railroad ties	1.50 million ft <sup>3</sup>
Timbers	.80 million ft <sup>3</sup>
Poles	.05 million ft <sup>3</sup>
Piling	.15 million ft <sup>3</sup>
Total annual production	2.5 million ft <sup>3</sup>

Approximately 60 percent of this production (1.5 million ft<sup>3</sup>) was railroad ties, of which 90 percent were air seasoned and 10 percent Boulton dried. The remaining production (1.0 million ft<sup>3</sup>) was composed of timbers, poles, and piling that were seasoned by steam conditioning or Boulton drying. For purposes of calculating the volume of retort water generated in preparing material for treatment, it was assumed that 50 percent of the poles, piling, and timbers were steamed and 50 percent were Boulton dried.

Dry stock

Water generated (crossties)

$$.25 \text{ gal/ft}^3 \times 1.35 \text{ million ft}^3 = 337,500 \text{ gal.}$$

Boultonized stock

Water generated (crossties)

$$1.5 \text{ gal/ft}^3 \times 150,000 \text{ ft}^3 = 225,000 \text{ gal.}$$

Water generated (other stock)

$$2.0 \text{ gal/ft}^3 \times 500,000 \text{ ft}^3 = 1,000,000 \text{ gal.}$$

Steamed stock

Water generated (poles, piling, etc)

$$6.0 \text{ gal/ft}^3 \times 500,000 \text{ ft}^3 = 3,000,000 \text{ gal.}$$

$$\text{Total retort water/yr} = 4,562,500 \text{ gal.}$$

Other sources of wastewater associated with the wood treating operation were water used for cleaning purposes and plumbing leaks. A very conservative estimate



of the contribution of these sources to total flow at the RTC plant is 0.1 gallons per cubic foot, or about 250,000 annually.

#### Recapitulation

Sources and volumes of wastewater are summarized in Table 2 by type, either process or non-process water. Process water is water that has been in contact with the products of the process or the chemicals used therein. Non-process water is water that has not been polluted. In fact, water from all sources at the St. Louis Park facility became comingled and exited the plant from a common outfall.

#### Rationale for Estimates

The estimates in Table 2 are conservative. Correspondence from Mr. Finch to Mr. Hennessey dated September 30, 1970 (Bates No. 016011) concerning the purchase of a separator states that the maximum plant discharge would be "200 gpm but would normally be less than 100 gpm." Those discharge rates correspond to daily flows of 144,000 to 288,000 gallons. A maximum flow of 200 gpm (288,000 gallons/day) is also mentioned in a letter dated October 28, 1970, from Mr. Kays, St. Louis Park Water and Sewage Superintendent, to Mr. Finch. This letter implies that this flow rate did not include stormwater.

Table 2. Estimate of annual wastewater volume from  
St. Louis Park Plant (gal).

<u>Source of Water</u>	<u>Process</u>	<u>Non-Process</u>
Compressor colling water	3,060,000	
Condenser cooling water		2,400,000
Steam condensate		6,506,000
Boiler blowdown		562,500
Stormwater - non-process		26,463,000
Stormwater - process	1,838,000	
Sulfate water	546,000	
Wet cut	234,000	
Quenching water	1,440,000	
Wood preservation		
Treating process	4,562,500	
Cleaning water, leaks	<u>250,000</u>	
Sub-total	11,930,500	35,931,500
Total annual flow	47,862,000	
Daily flow	159,540	

A memorandum to Mr. P. C. Reilly from Mr. Hennessy dated March 23, 1971 (pages 303233-40) gives a summary of the pollution problems and waste management practices at the various Reilly plants. A monthly flow rate of 1,155,000 cubic feet per month is mentioned for the Minnesota Street Plant located in Indianapolis. This rate corresponds to a daily flow volume of about 289,000 gallons.

In a memorandum to Mr. Courtney from Mr. Danz dated November 30, 1938, drainage from the St. Louis Park plant is reported to have been 50 gpm. The memorandum specifically states that most of the water was coming from the treating plant and suggests that the flow did not include any rain-water. A flow rate of 50 gpm corresponds to 72,000 gallons per day, depending upon plant operating schedule. This daily volume exceeds the above estimate for dry-weather flow.

Flow data included in the Reilly documents (SLP1-1) for two 24-hour sample periods during January, 1941, showed dry-weather discharges of approximately 50,000 and 58,000 gallons per day. Peak flows of 85 gallons per minute were recorded. No information on the plant operations in progress during the sampling period was provided.

Finally, the 1959 report of the Information and Technical Development Committee of the American Wood-Preservers' Association (AWPA Proc. 55:189-190) states that results of a survey conducted by that committee revealed that effluent discharges for wood preserving plants rarely exceed 50,000 gallons per day, while the ten tar distillation plants that responded to the survey all had discharge volumes greater than 250,000 gallons per day. Because this volume exceeds that which would be generated in the normal processing of coal tar, it is assumed that it includes single-pass cooling water.

Total process wastewater for the wood preserving operation was about 4,812,000 gallons per year, excluding boiler blowdown, coil condensate, and compressor cooling water, which was discharged through the ditch at the RTC plant.<sup>4/</sup>

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<sup>4/</sup> These latter sources of water are normally diverted away from plant operations through a separate outfall and, not being contaminated, are not counted as part of process wastewater volume. This volume of water is equivalent to about 1.9 gallons per cubic foot of production. The value is increased to 3.4 gallons per cubic foot when water from all sources is included in the calculations. A flow rate of 1.9 gallons per cubic foot may be compared to measured flow rates at similar plants of from 1.8 to 2.7 gallons per cubic foot.

### Pollutant Loading

Pollutant loadings, that is, the concentration of pollutants in the waste stream, can be determined exactly if the concentration and volume of wastewater are known. Documents from RTC files provide results of many analyses of wastewater for phenol and oil and grease content. For purposes of these calculations, an average phenol content of 200 mg/l and an average oil and grease content of 400 mg/l were used. Values both much higher and much lower are recorded in the file documents. Of course, the concentration at any given time depended upon the operations in progress within the plant and the extent to which process wastewater was diluted with stormwater or noncontact water from other sources.

It is particularly difficult to obtain a good estimate of oil and grease content of wastewater from analyses of occasional grab samples. Because creosote oil is heavier than water, it tends to settle out rapidly; so that while the actual loading may be in the thousands of parts per million--a situation not at all unusual for a plant with an ineffective oil-water separator--a grab sample taken in an area of slow flow may have an oil and grease content of less than 100 ppm. The oil that settles out during periods of normal flow is subsequently swept away during periods of heavy rainfall or flow of non-contact water from other sources.

<u>Parameters</u>	<u>Loadings based on total flow</u>	<u>Loadings based on dry-weather flow</u>
Wastewater flow (gal/day)	159,540	65,203
Phenol content (mg/l)	200	200
Oil-grease content (mg/l)	400	400
Daily pollutant loadings		
Phenol (lb.)	265	108
Oil and grease (lb.)	530	216
Annual pollutant loadings		
Phenol (lb)	79,500	32,400
Oil and grease (lb.)	159,000	64,800

#### Wastewater Treatment

Both primary and secondary treatment of oily process wastewater are necessary to meet existing discharge criteria. The purpose of primary treatment is to remove suspended and emulsified oils from the wastewater stream. Primary treatment typically consists of oil-water separation to remove free oil, followed by flocculation and filtration to remove emulsified oil. Secondary treatment usually involves biological or chemical oxidation of wastewater that has received primary treatment. Its purpose is to remove dissolved materials, such as phenols, sugars, and other organic substances. Secondary treatment of industrial wastewater was not widely practiced by American industry prior to about 1965. However, primary treatment technology, and especially oil-water separation, had attained a fairly high level of sophistication by the mid-1950's.

Primary treatment of oily process wastewater was developed and used by the petroleum industry prior to 1940. The focus of the early developmental work on wastewater treatment by this industry was efficient oil-water separation systems. Significant improvements in equipment efficiency resulted from a research project sponsored in 1948 at the University of Wisconsin by several petroleum refining companies. Modern oil-water separator designs are anchored to the basic design principles developed during that study. Design criteria, including details of oil-water separator design, were published by the American Petroleum Institute in 1959.

A review of flocculation and filtration technology was also included by the American Petroleum Institute in its 1959 publication. The technology described does not differ in a substantive way from that employed today. There have, however, been improvements in the chemicals employed to promote floc formation and agglomeration. Alum, lime and other metal salts, and clays of various types that were used in the 1950's are still used to some extent. However, these materials have been largely replaced by complex organic chemicals that are more efficient in promoting floc formation and which minimize the solids that must be disposed of.

Pollution control technology used by the wood preserving industry was adapted from the petroleum industry.

Pollution control was recognized by that industry as a problem that had to be addressed as early as 1951. A subcommittee charged with the responsibility of keeping the members of the American Wood-Preservers' Association informed on wastewater treatment and disposal was formed that year as part of a standing committee, the Information and Technical Development Committee. Reports of the subcommittee were published in the Proceedings of the American Wood-Preservers' Association. Fifteen such reports that focused on pollution control in the wood preserving industry were published during the period of 1952 through 1972.

An oil-water separator was installed at the St. Louis Park facility of RTC in 1941. The failure of this unit to abate pollution apparently was due to improper operation and maintenance. The design of the separator was similar to that used by the petroleum industry, except that it did not include a sloped hopper bottom, a feature that facilitates recovery of oil.

Reilly documents make reference to the poor condition of the baffles and the volume of sludge in the separator. Several documents indicate that the separator was full of sludge (C. F. Leshar to P. C. Reilly 5/23/68; C. F. Leshar to P. E. White 5/23/68; work order prepared by P. E. White entitled "Water Pollution Control" 5/20/68) and that it could not be pumped out (F. J. Mootz to T. E. Reilly 3/20/67). The separator would, of course, be totally ineffective in achieving the purpose for which it was designed under the



conditions described in those documents. If the separator were indeed full of sludge, it served only as a transit point for the flow of raw wastewater from the processing facilities to the drainage ditch across the south end of the plant property.

Failure to divert stormwater run-off from plant property upgrade from the processing facilities apparently contributed to the problems that the company experienced with the oil-water separator. Flooding of the plant, including the separator, is mentioned prominently in RTC documents. Construction of drainage ditches to channel stormwater away from the wood preserving and refinery facilities would have lessened this problem. Elevating the separator would have protected it from flooding.

Flocculation and filtration facilities were not installed at the St. Louis Park plant. Because only free oils are removed from wastewater streams by mechanical oil-water separation, oils in emulsion form would have been discharged from the separator even if it had been properly maintained and operated. Emulsified oils typically contribute from 200 to more than 2,000 milligrams per liter to total oil loadings of wastestreams from wood preserving plants.

Straw filters installed in the drainage ditch downstream from the separator may have reduced the free-oil content of the wastewater if they were properly maintained. These devices would not, however, reduce the concentration of emulsified oil in the wastestream.

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APPENDIX A

Wood Treating

### Effect of Products and Species

Railroad ties and piling are mentioned as products treated at St. Louis Park. Pressures of 150-200 psi are normally required for such products when creosote is the preservative, particularly for hardwood species. Approximately 80-90 percent of all ties are manufactured from hardwoods. Most piling are cut from softwood species, although a small percentage--about 10 percent--are oak.

Final retention of preservative varies from 6 to more than 20 pounds per cubic foot, depending upon product. Standards for hardwood ties are frequently based on sapwood penetration rather than retention of a fixed quantity of preservative per cubic foot. The exact standard varies somewhat among the various hardwood species used for tie production.

The distinction between full-cell and empty-cell processes lies primarily in the maximum retention of preservative possible by the two processes. Full-cell treatments are typically applied where the treated products will be exposed to severe biological hazard, such as marine piling. The empty-cell process is used for products--such as poles, timbers, construction piling, etc.--that will be placed in less severe service sites. The quantity of preservative required for these various products

is specified by standards of the American Wood-Preservers' Association (AWPA). Those standards, in turn, determine the process that must be used. Treatment cost is not the major factor that determines target retention.

### Conditioning of Wood for Treatment

Unseasoned wood of all species must be partially dried before it can be treated with a preservative in a pressure process. Air drying is the most commonly used method, but kiln drying, Boultonizing, vapor drying, and steaming may also be used. All methods of seasoning, or conditioning, are not permitted with all species.

#### Air Drying

The methods of conditioning used at St. Louis Park depend upon the species and products treated. Air drying is mentioned as the major method. The drying time reported-- 12 to 14 months--would be appropriate for railroad ties. Vapor drying and Boulton drying are also used for this product.

#### Steam Conditioning

The extent to which steam conditioning was used at St. Louis Park depends upon the quantity of softwood products treated. Steam conditioning is not permitted with the usual range of hardwoods that make up most of railroad tie production. Therefore, if this process was used to any significant extent, softwood must have comprised some percentage of the plant's production.

This point is important because the volume of wastewater generated by a plant is directly affected by conditioning process. Steam conditioning is the process that generates the largest volume of process effluent. The greater part of the wastewater is steam condensate. The quantity varies with the duration of the steaming period, normally 8 to 12 hours, depending upon size of product and its initial moisture content. Wastewater volume is also greatly influenced by whether or not the retort is insulated. The other principal wastewater source is the water removed from the wood during steaming and the vacuum cycle which follows it. This amount is typically about 4 pounds per cubic foot of wood. By contrast, the quantity of steam condensate can be as large as several gallons per cubic foot.

#### Vapor Drying and Boulton Drying

Vapor drying and Boulton drying generate less wastewater than steaming. This is true because the only effluent source is the water removed from the wood. While the quantity of water actually removed from the wood by these processes is much larger than for steaming, total wastewater volume is much less.

In the Boulton process, the water vaporized from the wood goes to a condenser and collects--along with light oil fractions--in a "hot well." Oil entrained with the water is normally separated and reused. Water removed from wood by vapor drying is similarly processed. The vapors from the process are condensed, the organic solvent separated for reuse, and the water discarded. Both Boulton and vapor drying are more expensive than air drying, but are frequently used when the supply of air dried stock is inadequate to meet orders for treated products.

Vapor drying was not used by RTC at its St. Louis Park plant.

### Treating Processes

In the full-cell process (Figure A-1), an initial vacuum is applied to the charge for a period of about 30 minutes. At the end of this period, and while still maintaining the vacuum, the vessel is filled with preservative. The vacuum is released and pressure equal to 50 to 250 psi, depending upon species, is applied to the system. Pressure is maintained until the required gross adsorption is achieved.

At the end of the pressure cycle, the pressure is reduced to atmospheric level, the preservative returned to storage, and the treated wood often subjected to a final vacuum to remove excess preservative from the surface

## FULL CELL PROCESS

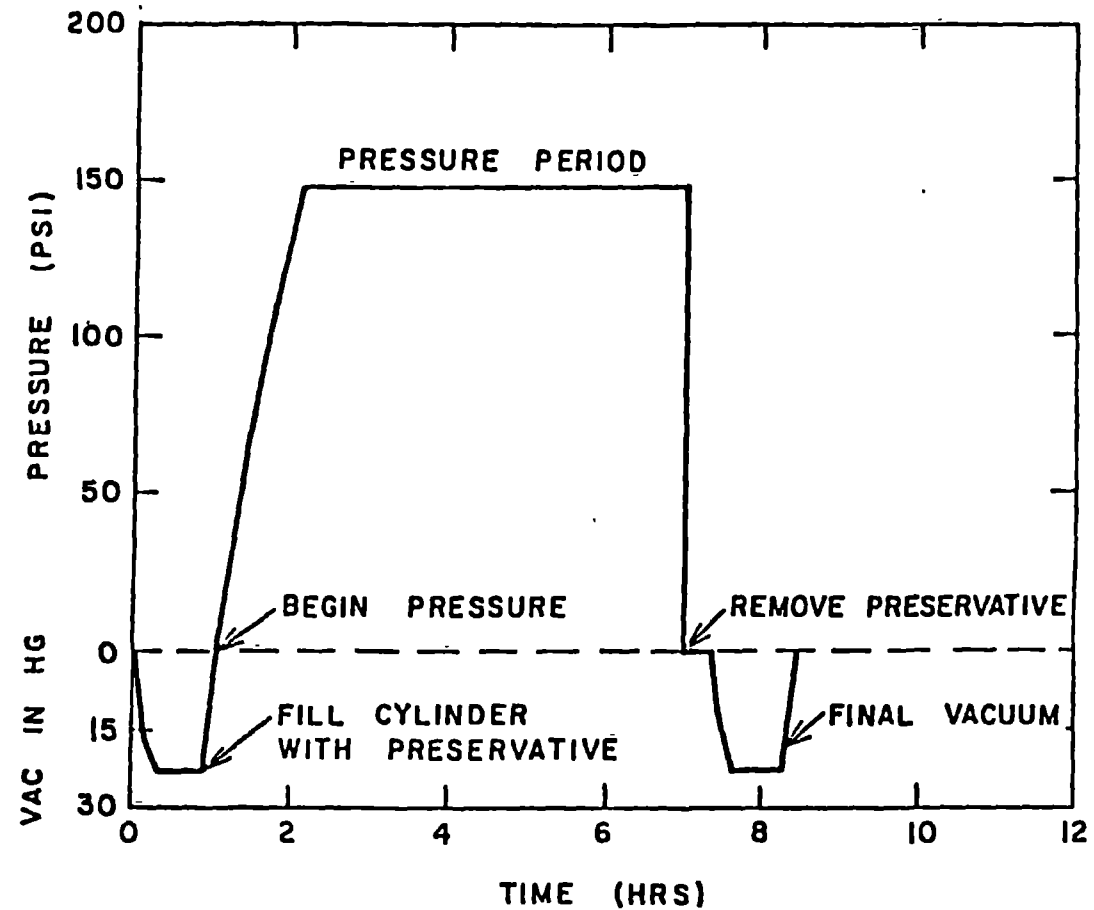


Figure A-1. Schematic showing the treating schedule for full cell treatment.



of the stock. The vacuum is released, the door of the vessel opened, and the treated wood removed. Retentions achieved by the full-cell process vary from 20 to 30 pounds per cubic foot for most species.

In the empty-cell process the retort is filled with preservative while either at ambient conditions or under an initial air pressure of 15 to 75 psi (Figure A-2). The remainder of the treating schedule is the same as that described for the full-cell process. Retentions achieved by the empty-cell process range from 6 to 12 pounds per cubic foot, depending upon the specifications of the customer.

## EMPTY CELL PROCESS

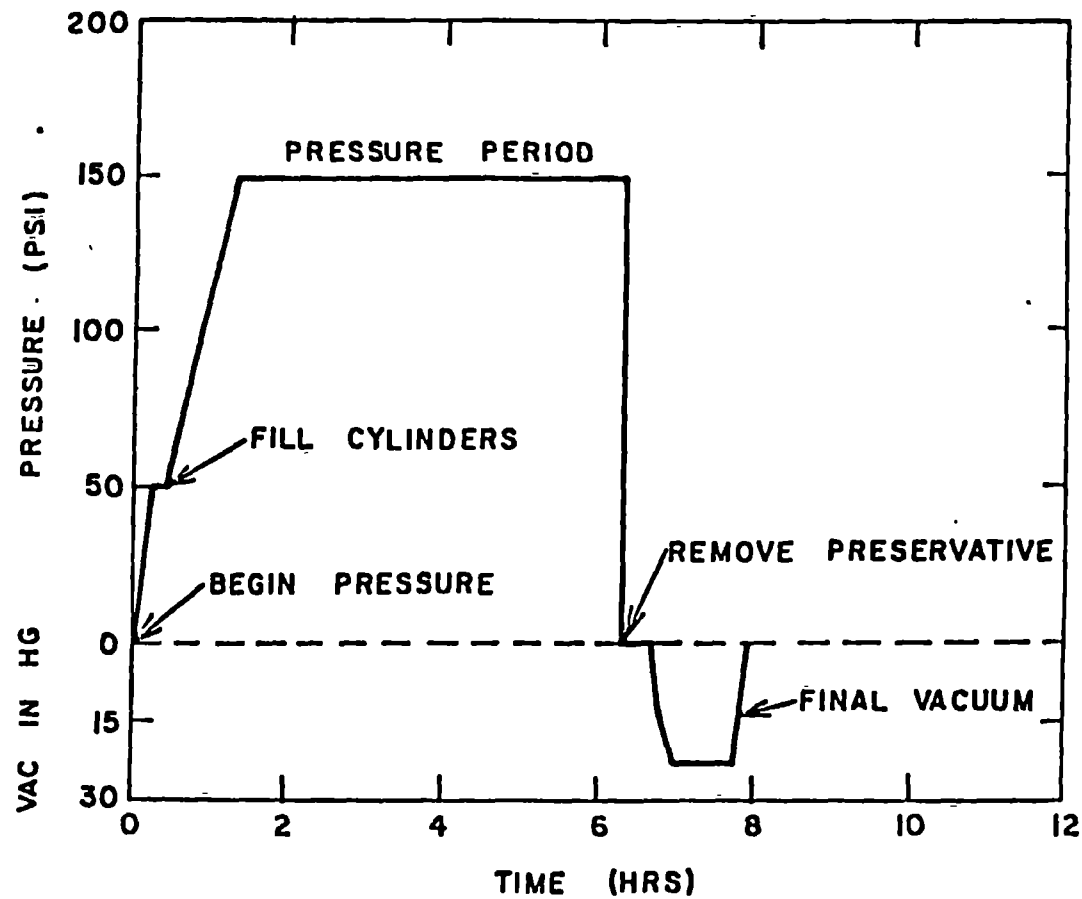


Figure A-2. Schematic showing the treating schedule for empty-cell treatment.

APPENDIX B

Preservatives

## Preservatives

### Creosote

The use of creosote at St. Louis Park was a logical development for an operation that included a tar distillation facility. Creosote had been used as a preservative in the U.S. for approximately 42 years prior to 1917 when its use for this purpose was begun at St. Louis Park.

Creosote is a blend of several of the fractions produced during the distillation of coal tar. Because of its complex chemical composition--consisting, as it does, of some 200 "major" constituents and several thousand "minor" components--and because its composition varies from batch to batch, creosote traditionally is described in terms of its physical properties. The most important in this regard are specific gravity, water content, benzene-insoluble matter, and the percentage distilling within fixed temperature ranges.

Three grades, each of which is described in appropriate AWWA specifications in terms of these properties, are recognized within the industry. They are:

- P-1 Creosote for land and fresh water use.
- P-7 Creosote for brush or spray applications.
- P-13 Creosote-coal tar blend for marine use.

In addition, P-1 creosote may be blended with coal tar in the ratios of 80:20, 70:30, 60:40, or 50:50; or it may be combined with petroleum in the same ratios, although

the ratio of 50:50 is most commonly used. The choice between petroleum and coal tar as a diluent for creosote in crosstie treatments is generally based on local costs including freight. The creosote-petroleum solutions are used to treat certain products, such as railroad ties, the service exposure of which is such that straight creosote or creosote-coal tar are not needed for protection.

#### Pentachlorophenol

Pentachlorophenol is also mentioned as a preservative that received limited use at St. Louis Park. This preservative is commonly applied to wood as a 5-7 percent solution in a petroleum carrier. The solvent can be a fuel oil--a #2 oil is frequently used--or a lighter solvent, such as mineral spirits, blended with high-solvency materials such as ketone bottoms. Penta in light solvents is commonly used for millwork and other products where a clear, paintable surface is needed. Known in the trade as light solvent treatments, this treatment is not used for heavy-duty products such as crossties and piling.

#### Characterization of Creosote

Creosote is one of the major products of tar distillation. It is a blend of the various distillates designed to impart specific physical characteristics that meet standards of the American Wood-Preservers' Association. A typical blend used to meet the provisions of Standards P1, P2, and P13 might be as follows:

AWPA P-1

	<u>Percent</u>
Solvent naphtha	10
Naphthalene still residue	35
Uncorrected creosote	55

AWPA P-13

	<u>Percent</u>
Solvent naphtha	5
Naphthalene still residue	35
Uncorrected creosote	45
Heavy oil	15

AWPA P-2

	<u>Percent</u>
Coal tar	10
Uncorrected creosote	90

Some formulations may employ slightly different ratios or omit the naphtha solvent or still residues.

As mentioned elsewhere, creosote and blends of creosote and coal tar are normally described in terms of their physical properties. AWPA specifications for creosote for various uses are given in Table B-1. The principal differences among creosotes for the three uses shown are in specific gravity and the fraction of the oil

distilling within various temperature ranges. This is likewise the case for creosote-coal tar solutions, AWWA specifications for which are shown in Table B-2.

A comparison of physical properties of coal tar and creosote in Table B-3 indicates much higher distillation residue for coal tar. Various proportions of coal tar are mixed with creosote to treat crossties, switch ties, and piling where surface appearance is not critical.

At least 200 chemical compounds have been identified in creosote. Although the chemical composition of this material varies for reasons discussed above, it is generally agreed that several thousand different compounds could perhaps be identified with modern analytical instruments. Most of these are present in very small amounts, however.

The greater part of the composition of creosote consists of neutral fractions. Tar acids, such as phenol and the cresols, as well as such tar bases as pyridenes, quinolines, and acridines, constitute a rather small percentage of the total weight of creosote. Unlike the neutral fractions, the tar acids and bases are usually soluble in water and hence contribute very little to the efficacy of creosote as a wood preservative. It follows from the foregoing statements that the chemistry of creosote and that of the coal tar neutral fractions are quite similar. So, for that matter, is the chemistry of the parent material--coal tar. Compositional data for coke-oven coal tar from three sources are given in Table B-4.

The chemical oil fraction shown in Figure B-3 can be processed into various products. The so-called crystal-free neutral oil and tar acid oil are used in the manufacture of animal repellents, insecticides, acaricides, disinfectants, etc. The collection and marketing of these fractions was in earlier years a common practice. However, today, only one company sells neutral oil, the market for this product having been taken over by modern pesticides that are more effective and frequently less expensive than those made from coal tar products.

There were 64 producers of coal tar in the United States in 1972 and 24 tar distillation plants producing creosote. A list of the latter plants, with production data, is given in Table B-5.



Table B-1. Physical properties of creosote and its fractions.<sup>a</sup>

	AWPA Standard Number					
	P1-65 <sup>a</sup>		P7-72 <sup>b</sup>		P13-65 <sup>c</sup>	
Water % volume	< 1.5		< 1.0		< 1.5	
Xylene, insoluble, % wt.	< 0.5		< 0.5		< 0.5	
Specific gravity 38/15.5°C						
Whole creosote	> 1.050		> 1.060		> 1.080	
Fraction 235-315°C	> 1.027		--		> 1.030	
Fraction 315-355°C	> 1.095		--		> 1.105	
Residue above 355°C	--		--		> 1.160	
Distillation, % by wt.	Min.	Max.	Min.	Max.	Min.	Max.
Up to 210°C	--	2.0	--	1.0	--	2.0
235°C	--	12.0	--	10.0	--	12.0
270°C	20.0	40.0	--	--	20.0	40.0
315°C	45.0	65.0	--	--	45.0	65.0
355°C	65.0	82.0	65.0	--	65.0	75.0
Shall remain fluid and crystal free after 3 hrs. at 5°C.						

<sup>a</sup>For land and fresh water use.

<sup>b</sup>For brush or spray application.

<sup>c</sup>For marine (coastal water) use.

Table B-2. AWWA Specifications for creosote-coal tar solutions.<sup>a</sup>

	Grade			
	A	B	C	D
Composition				
Creosote	<80	<70	<60	<50
Coal Tar	--	--	--	--
Water (% by volume)				
Xylene, insol.	> 3.0	> 3.0	> 3.0	> 3.0
(% by weight)	> 2.0	> 3.0	> 3.5	> 4.0
Coke residue	> 5.0	> 7.0	> 9.0	> 11.0
(% by weight)				
Specific Gravity 38/15.5°C				
Whole oil	1.06-1.11	1.07-1.12	1.08-1.13	1.09-1.14
235-315°C	1.025	1.025	1.025	1.025
315-355°C	1.085	1.085	1.085	1.085
Residue	--	--	--	--
Distillation				
To 210°C	5	5	5	5
To 235°C	25	25	25	25
To 270°C	--	--	--	--
To 315°C	36	34	32	30
To 355°C	60	56	52	48
Residue	--	--	--	--

<sup>a</sup>AWWA Book of Standards (P2-68).

Table B-3. Comparison of the physical properties of coal tar and creosote.

	Creosote	Coke Oven Coal Tar
Benzene Insoluble, % wt.	0.99	4.6
Specific Gravity 38/15.5°C		
Whole oil	1.102	1.180
235-315°C	1.054	-----
315-355°C	1.133	-----
Distillation, % wt.		
To 210°C	1.87	1.8
To 235°C	6.89	7.1
To 270°C	19.39	18.2
To 315°C	49.8	28.3
To 355°C	72.58	41.9
Residue above 355°C	26.67	57.6

Table B-4. Average chemical composition of three coke-oven coal tars.

Component	British	German	American
Water, %	4.9	2.5	2.2
Carbon, % (on dry tar)	90.3	91.4	91.3
Hydrogen, % (on dry tar)	5.5	5.25	5.1
Sulfur, % (on dry tar)	0.84	0.75	1.2
Nitrogen, % (on dry tar)	0.95	0.86	0.67
Ash, % (on dry tar)	0.24	0.15	0.03
Toluene insolubles, % (on dry tar)	6.7	5.5	9.1
Components wt., % (on dry tar)			
Benzene	0.25	0.4	0.12
Toluene	0.22	0.3	0.25
o-xylene	0.04	--	0.04
m-xylene	0.11	0.2	0.07
p-xylene	0.04	--	0.03
Ethylbenzene	0.02	--	0.02
Styrene	0.04	--	0.02
Phenol	0.57	0.5	0.61
o-cresol	0.32	0.2	0.25
m-cresol	0.45	0.4	0.45
p-cresol	0.27	0.2	0.27
Xylenols	0.48	--	0.36
Higher-boiling tar acids	0.91	--	0.83

Table B-4.(continued).

Component	British	German	American
Components wt., % (on dry tar) (continued)			
Naphtha fraction (bp 150-200°C)	1.18	--	0.97
Naphthalene	8.94	10.0	8.80
1-methylnaphthalene	0.72	0.5	0.65
2-methylnaphthalene	1.32	1.5	1.23
Acenaphthene	0.96	0.3	1.06
Fluorene	0.88	2.0	0.84
Diphenylene oxide	1.50	1.4	
Anthracene	1.00	1.8	0.75
Phenanthrene	6.30	5.7	2.66
Carbazole	1.33	1.5	0.60
Tar bases	1.77	0.73	2.08
Medium-soft pitch (70°C, R and B softening pt.)	59.8	54.4	63.5

Table B-5. Creosote production in the United States in 1972 by plant.<sup>a</sup>

	Est. Plant Capacity	Est. Annual Production
	(M lb./yr.)	(M/lb.)
<u>Allied Chemicals Corporation</u>		250-350
Detroit Michigan	100-200	
Ensely, Alabama	100-200	
Ironton, Ohio	100-200	
<u>Koppers Company, Inc.</u>		350-450
Cicero (Chicago), Illinois	100-200	
Follansbee, West Virginia	100-200	
Fontana, California	200-300	
Houston, Texas	10-20	
Portland, Oregon	10-20	
Kearny (Seaboard), N. J.	10-20	
St. Paul, Minnesota	10-20	
Swedeland, Pennsylvania	10-20	
Woodward, Alabama	100-200	
Youngstown, Ohio	100-200	
<u>Reilly Tar &amp; Chem. Corporation</u>		50-100
Cleveland, Ohio	10-20	
Granite City, Illinois	10-20	
Ironton (Provo), Utah	10-20	
Lone Star, Texas	10-20	
Chattanooga, Tennessee	10-20	
<u>USS Chemicals</u>		250-350
Clairton, Pennsylvania	100-300	
Fairfield, Alabama	100-200	
Gary, Indiana	100-200	
<u>The Western Tar Prod. Corporation</u>		20-40
Memphis, Tennessee	10-20	
Terre Haute, Indiana	10-20	
<u>Witco Chemical Corporation</u>		10-2-
Point Comfort, Texas	10-20	
Total Annual Production (1972)		1,150

<sup>a</sup>Anonymous, 1980.

*Sierke*

**Summary Of Expected Testimony On  
Principles Of Contaminant Transport In The  
Ground Water System With Application To  
A Coal Tar Derivative Contamination  
Problem, St. Louis Park, Minnesota**

**Submitted In Accordance With Paragraph 6  
Of The Case Management Order of the  
Honorable Paul A. Magnuson**

**Hans-Olaf Pfannkuch  
Professor  
Department of Geology  
and Geophysics  
University of Minnesota  
Minneapolis, Minnesota**

**1.0.0.0    General Discussion of Contaminant Transport in the Aquifer Systems of the St. Louis Park Area.**

**1.1.0.0    Statement of Objective:**

**The scope of this report is to:**

- (1)    provide an understanding of the hydrogeology in the St. Louis Park area, including a brief review of geology, groundwater flow systems and groundwater chemistry**
- (2)    provide an understanding of the processes of contaminant transport pertinent to the St. Louis Park contamination problem.**
- (3)    discuss the extent of contamination and possible remedial measures that can be taken to mitigate the impact of the contamination.**

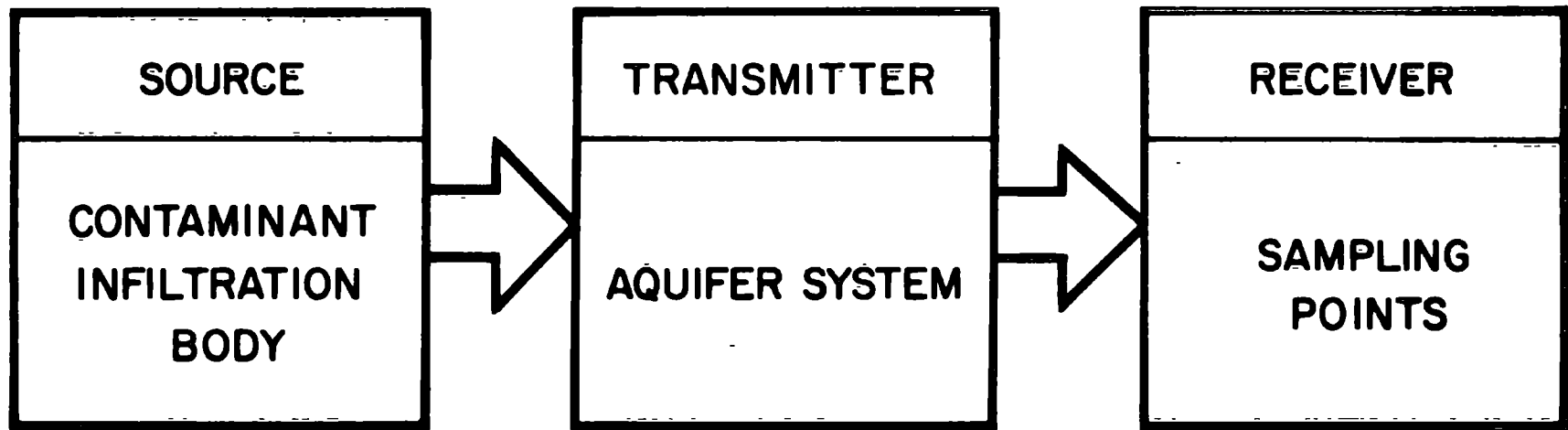
**The basic objective in assessing a groundwater contamination problem as in the St. Louis Park area is to:**

- (1)    identify the contaminant(s) and the location of the contamination source area**
- (2)    determine the areal and vertical extent of the contamination**
- (3)    describe past levels of concentration and forecast expected levels at critical locations.**
- (4)    provide technical information to design actions to prevent contaminant migration and further degradation of the groundwater**

**These objectives furnish a basis on which present and future remedial action can be planned.**

**A useful illustration of the relationship between a contaminant body, the hydrogeologic system, and the mass transport process is to use the analog of a communication system with a source, transmitter and receiver.**





**FIG. GENERALIZED SYSTEMS DIAGRAM FOR GROUND WATER CONTAMINATION CASE**

Figure \_\_ is a systems diagram of the source-transmitter-receiver analog applied to contamination cases in aquifer systems.

The original contamination body acts as the signal source which is transmitted through the aquifer system. In the aquifer system the signal can be modified or modulated in various ways. The contamination eventually is detected or measured as an output at the receiver. An output receiver may be a naturally accessible location (surface bodies of water, seep or spring) or an artificially installed structure (monitoring wells, or municipal and private water wells.)

#### 1.2.0.0. Methodology of Approach and Means of Investigation

Groundwater contamination usually is discovered after a water supply has been contaminated. Since a source for the contamination may be difficult to determine at first, the groundwater system must be examined to provide more information about the contamination and sources.

The approach in such an examination is three fold:

- (1) the characteristics and conditions of the aquifer system are identified and the present situation is assessed.
- (2) the past performance of the aquifer system is reconstructed on the basis of records and an understanding of the processes in operation. The combination of the present state and the reconstructed past, including the identification of sources, serves as the basis to project contamination patterns expected in the future under prevailing conditions.

- (3) From this reconstruction models are designed to demonstrate the consequences of different management plans and compare alternative options for remedial action.

Groundwater flow and mass transport phenomena in aquifers are not open to direct inspection. Therefore, much of the information dealing with groundwater processes is based on several subsurface techniques.

1.2.1.0 Subsurface Investigations:

Subsurface geologic and hydrologic investigation obtain the bulk of the information about the subsurface conditions by using geophysical surveys and techniques or drilling boreholes.

Geophysical surveys, such as electrical resistivity, tend to be less expensive to conduct than physically sampling the subsurface deposits. Geophysical interpretation of the results can provide a variety of information, but may be limited in its use at a site by man-made interferences, such as electric wires, buried objects as pipelines or cables, and buildings.

Therefore, drilling boreholes for sampling or construction of monitoring wells is necessary. Great care must be exercised in site selection for borings, as well as the construction of monitoring wells, if water levels and water samples are to reflect the subsurface conditions realistically.

Samples collected from boreholes are used for :

- (1) geologic interpretation to help understand the geologic medium through which water is moving,
- (2) hydrologic interpretation to determine the characteristics of the aquifer's water bearing capacity and the ease of water movement through the geologic medium, and
- (3) chemical interpretation to determine the soil chemistry and the degree of soil contamination.

Water levels measured at monitoring wells are converted to elevations and plotted on maps. These elevations are referred to as "potentiometric heads." Then, contour lines of equal potentiometric head can be constructed on the map to indicate the shape of the "potentiometric" surface. Groundwater flow lines can be constructed at right angles to the equipotential head lines if certain simplifying assumptions apply.

Chemical analyses of water samples from monitoring wells permit the determination of contaminant distribution in the aquifer.

Extreme care in the sampling, sample preparation, handling, and transport is necessary to avoid cross contamination or loss of constituents with the monitoring procedure. This would invalidate the analyses and make the sample unrepresentative of downhole conditions or and, therefore, unuseable for a correct interpretation.

Only rigorously devised sampling protocols and tight quality assurance and quality control procedures can assure that the integrity of measurements and sample analyses be maintained.

1.2.2.0 Hydrogeologic Quality Assurance/Quality Control

The basic idea in hydrologic quality assurance is to verify that the sampling point (borehole, monitor well) truly represents the aquifer at that point. This means that drilling, sampling, and well installation have to be carried out under strict quality control principles and at all cost have to avoid introducing cross contamination.

Most of the monitoring wells in the shallow aquifers (located in an area of approximately four square miles surrounding the former Reilly site) were installed under the auspices of the U.S. Geological Survey. A majority of high frequency measurements have been carried out by the USGS. Their methodology is based on formal procedures that have been developed over a long time by the USGS. The method consists of a well defined protocol, redundancy in measurements where feasible, cross checks between methods, and timely analysis to permit corrective measures or repeat sampling. Once the quality of the hydrologic network and its operation is assured other observation points or wells for which no original protocol

existed can be integrated into the system if their data prove to be consistent with the rest.

#### 2.0.0.0 Hydrogeology of the St. Louis Park Area

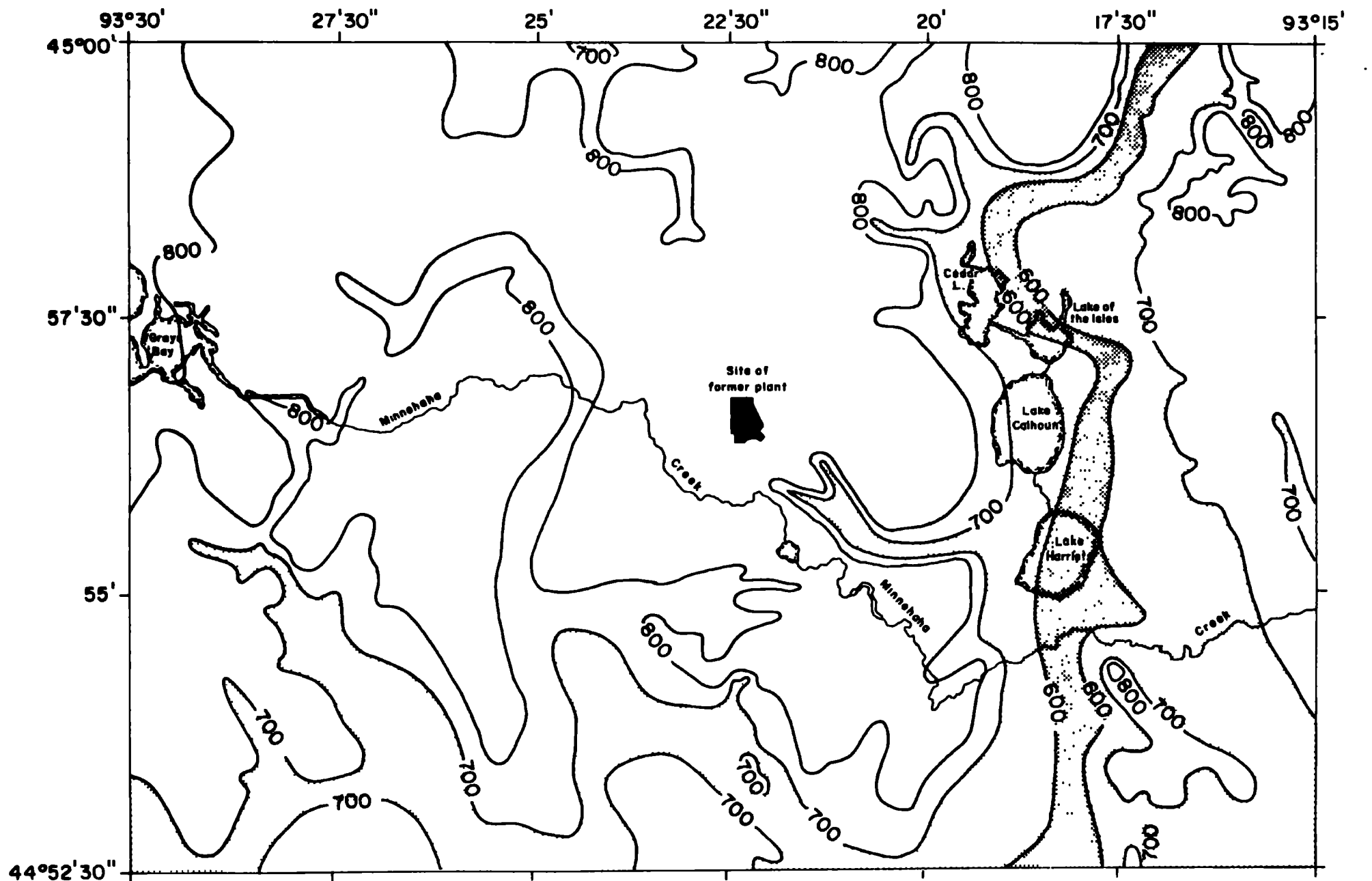
##### 2.1.0.0 Geology

The local and regional geology provide the framework within which hydrologic processes occur. Many geologic processes that have operated over time shape the geology of a site. Historical knowledge of the past geologic events provides important information in understanding the present and past hydrologic behavior of a groundwater aquifer. In order to simplify working with various geologic units, a basic subdivision of the units is made:

- (1) Surficial deposits are near surface deposits, usually unconsolidated and less compact. They are the result of recent deposition or of disintegration of solid rocks through weathering.
- (2) Bedrock units are consolidated and indurated former sediments or compact and dense crystalline rocks.



Surficial Deposits: The surficial deposits are shown as the uppermost portion of the lithologic column in figure \_\_. They consist of glacial drift materials and can be subdivided into three units from top to bottom.

- (1) Upper Drift: consisting of fill, lake deposits, silt and peat deposits. Intermixed in the upper portion are man-made fill materials.

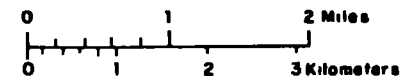


EXPLANATION

— 700 — BEDROCK CONTOUR - Shows altitude of bedrock surface Contour interval 100 feet National Geodetic Vertical Datum of 1929

 Altitude of bedrock surface is at or deeper than 600 feet  
 Altitude of bedrock surface is at or deeper than 700 feet

Shaded Areas  
 Delineate the  
 Bedrock Valleys



  former plant

**Figure** Preliminary Bedrock Topography, Minneapolis South and Hopkins Quadrangles (Modified from Hult, M.F., and Schuchberg, M.E., 1984, U.S. Geological Survey, Preliminary Bedrock Topography Map, U.S. Geological Survey Water Supply Paper 2211).

- (2) Middle Drift: consisting of glacial sand and gravel.
- (3) Basal Drift: consisting of till, silty sand, outwash, valley fill deposits, and deeply weathered bedrock.

The glacial processes that operated in the St. Louis Park area were both erosional and depositional. The present shape of the bedrock surface underlying the surficial deposits in St. Louis Parks is a direct consequence of glacial erosion.

Glacial erosional processes included the scouring of the surface by the glaciers and also meltwater erosion, which together cut deep valleys into the bedrock surface. The effects of glacial erosion on the pre-glacial bedrock surface in St. Louis Park are a partial removal of several upper bedrock units, highly irregular bedrock surface, and the incision and/or enlargement of bedrock valleys.

The glacial surficial deposits overlying the bedrock surface in St. Louis Park result from direct melting and deposition of the glacier ice and its contents. Consequently, glacial deposits make up an assorted mixture of all size classes (clays, sands, gravels, tills, etc). The effects of glacial deposition on the preglacial bedrock surface in St. Louis Park are varying thicknesses of assorted materials on the bedrock surface and the filling in of bedrock valleys.



DEPTH BELOW  
LAND SURFACE, IN FEET

HYDROGEOLOGIC  
UNIT

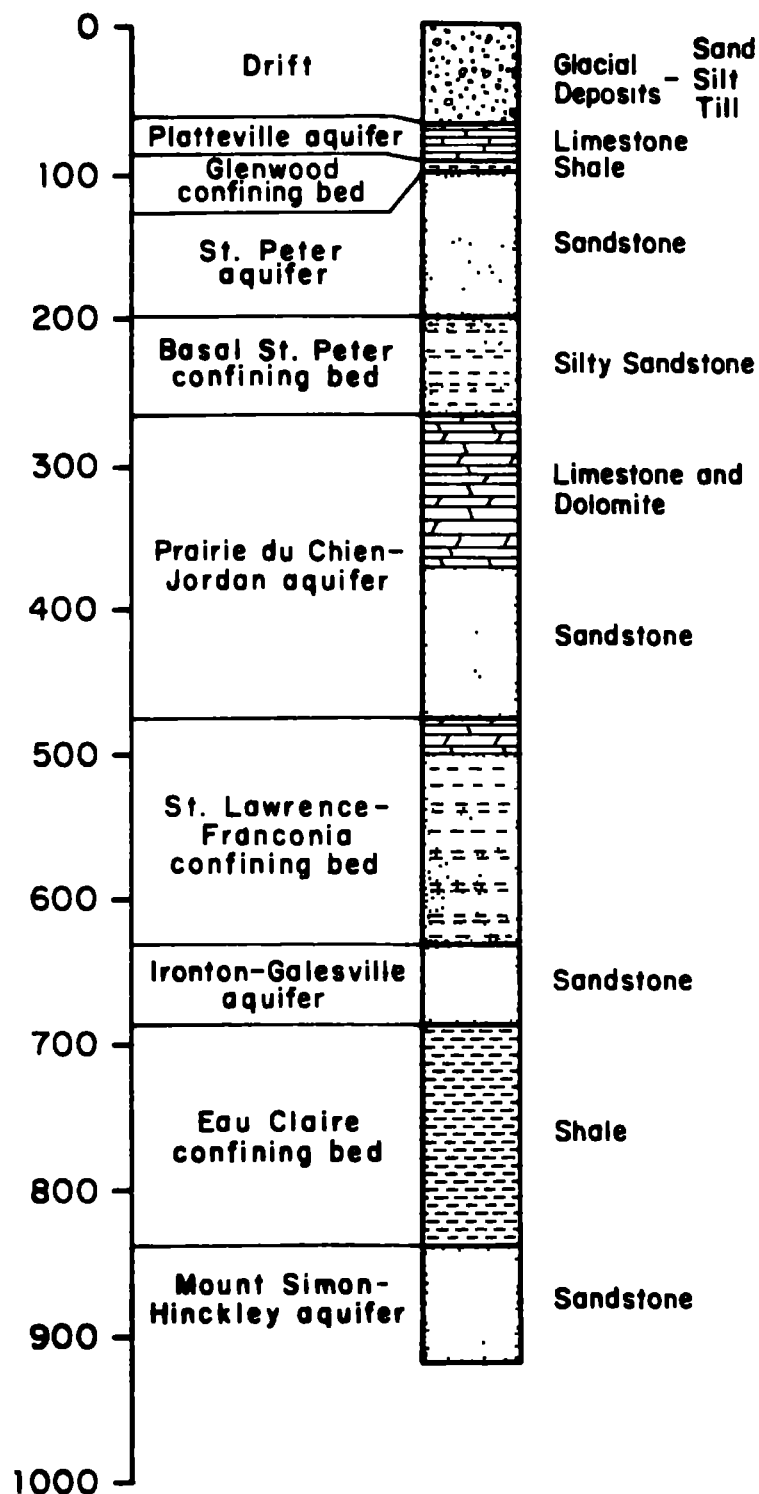
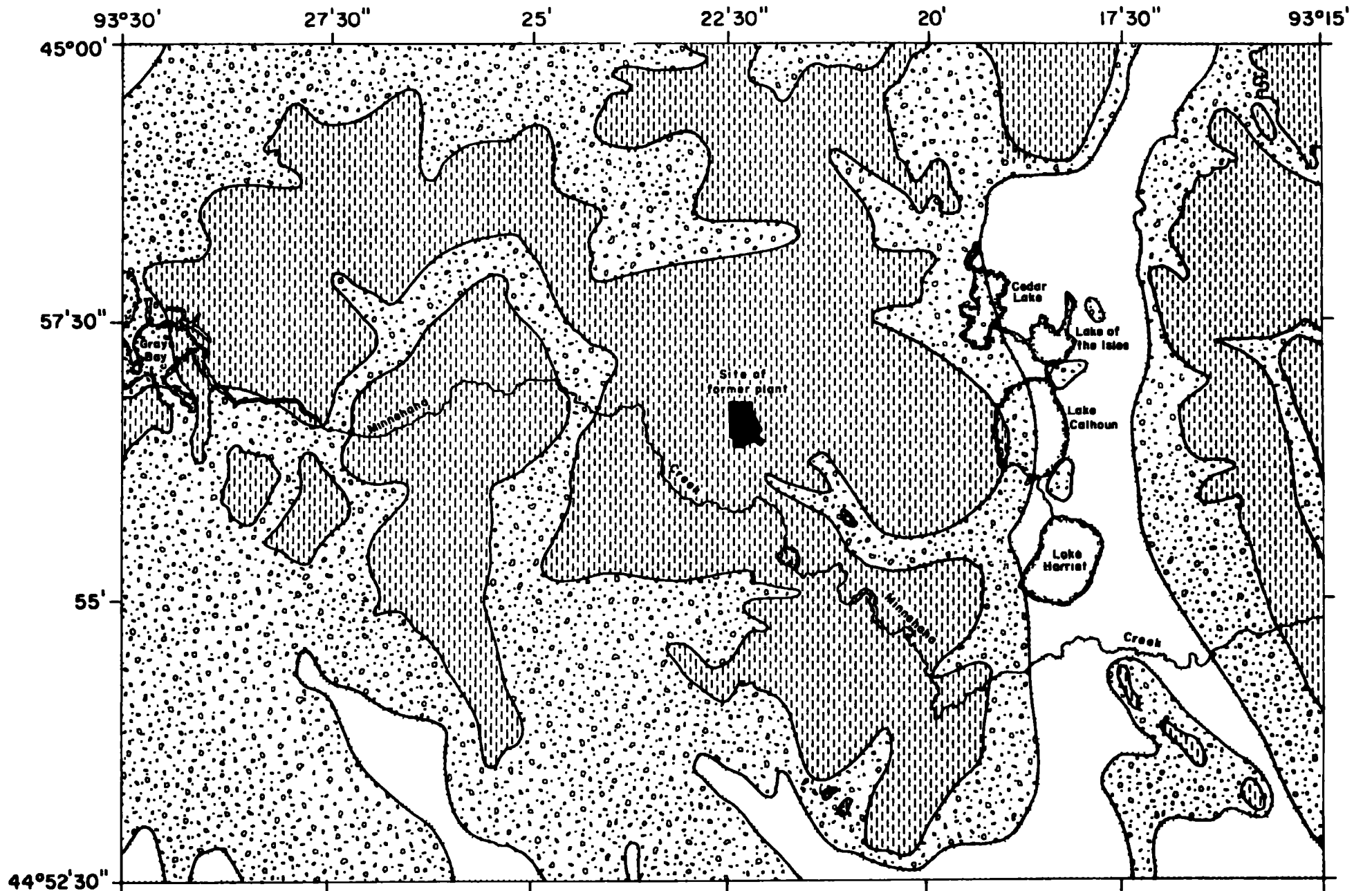





FIG. . GENERALIZED STRATIGRAPHIC COLUMN BASED  
ON WELL LOGS FROM W 23 ON SITE  
(AFTER HULT AND SCHOENBERG 1984)

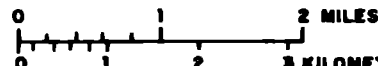




Base from Minnesota Department of Highways General Highway Map of Hennepin County, 1977

#### CORRELATION OF MAP UNITS

-  Platteville and Glenwood Formations, undivided
-  St. Peter Sandstone
-  Prairie du Chien Group

#### EXPLANATION

-  0 1 2 MILES  
0 1 2 KILOMETERS
-  Approximate geologic contact
-  Site of former plant

ORDOVICIAN

**Figure** Preliminary Bedrock Geology, Minneapolis South and Hopkins Quadrangles (Modified from Hult, M.F., and Schoenberg, M.E., 1984, U.S. Geological Survey Preliminary Bedrock Geology Map, U.S. Geological Survey Water-Supply Paper 2211).

Although surface expressions of the bedrock valley are not recognizable because of subsequent glacial deposition, the existence of these buried bedrock valleys are hydraulically important to contaminant transport and will be discussed in greater detail in a later section.

Bedrock Units: The geologic column of bedrock units in the St. Louis Park area is shown in figure \_\_. An areal map is shown on figure \_\_. They consist of a sequence of sandstones, shales and limestones which is typical of the marine environments in which they were deposited.

The sandstone represents near shore deposition, the shales deposition into the more quiescent sea away from the shore, and the limestones and dolomites are chemical precipitates occurring far out in the sea where land generated particulate sediments do not reach. The vertical repeat of this lithologic sequence is due to cyclic fluctuations of sea level which provoked an advance or retreat of the shoreline. Hence, a single location such as St. Louis Park would, over geologic time, be a near shore, shallow sea, or deep sea environment depending on where the shoreline was located at a given time.

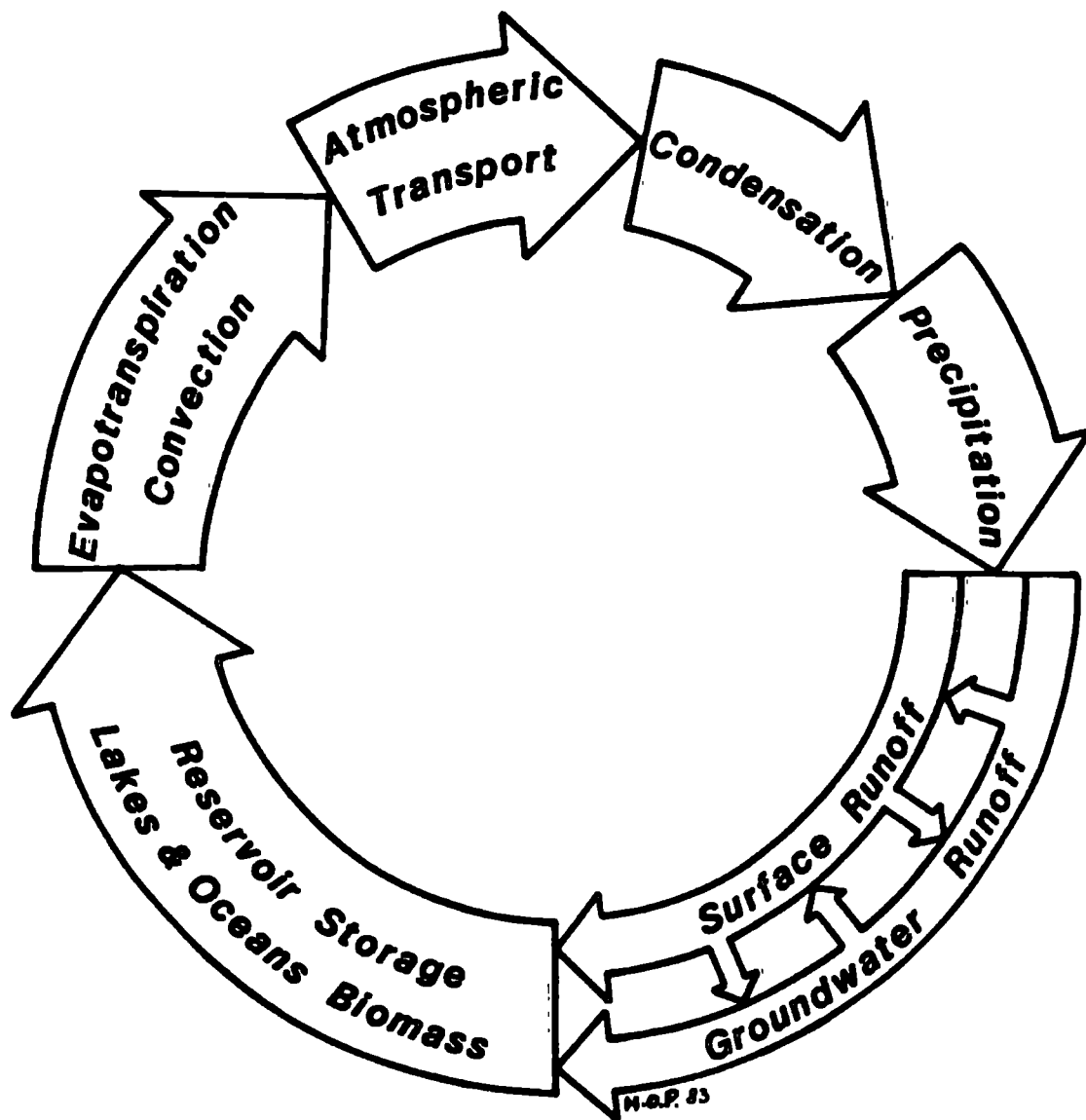
The bedrock units in the St. Louis Park area are part of a basin structure. The basin, shaped like an oval bowl with the elongated axis trending in a north-easterly

direction, is about 90 miles in length and about 40 miles in width. The deepest portion of the basin underlies the City of Minneapolis. Therefore, the bedrock sediments deposited within the basin have a very slight slope towards this center. The slope, however, is locally so small that it does not influence hydraulic gradient or groundwater flow in any significant way.

The surficial and bedrock units shown in figure \_\_ together comprise six aquifers, separated by four aquitards or confining beds. A more detailed description of the hydrologic properties and characteristics of the different units will be presented in section 2.2.5.0.

#### 2.2.0.0 General Groundwater Hydrology

Hydrogeology is the combination of the geological features discussed in the previous section with hydrologic parameters to create the environment in which groundwater can flow. It recognizes that groundwater flow is driven by the hydrologic cycle from recharge to discharge areas. The units through which groundwater flows are the aquifers. Aquifers obtain their hydrologic characteristics from the geologic nature of the rocks they consist of and the geologic history during which these characteristics may have been altered.



**Figure**      **Generalized Flow Diagram of the Hydrologic Cycle**

#### 2.2.1.0 Hydrologic Cycle:

Groundwater flow systems are intimately connected with the hydrologic cycle and driven by the runoff produced by precipitation. (Figure \_\_ is a schematic view of the hydrologic cycle in an unstressed state i.e., no artificial withdrawals.) In the simple sense, the amount of water available for recharge into an aquifer is the difference between precipitation and surface runoff away from the aquifer's recharge area.

Water in the groundwater system is not lost to the hydrologic cycle. Groundwater systems discharge water to surface bodies of water.

#### 2.2.2.0 Aquifer Systems:

An aquifer is a geologic deposit with sufficient groundwater saturation, void space, and adequate hydraulic transmissivity to produce a sustained discharge of water to wells or natural springs. In the context of contamination studies, the definition has to be enlarged to comprise units that might not be considered for groundwater supply, but that are capable of transmitting significant amounts of contaminants. As a matter of fact, the entire system, consisting of aquifers separated by aquicludes and aquitards, needs to be defined in terms of its combined capacity to transmit pollutants. Aquicludes traditionally were considered to be totally

impermeable to groundwater flow. However, the notion of the perfect insulator does not hold. Therefore, it is more appropriate to call these units aquitards, which allows for the fact that some mass transport through the unit occurs, albeit at much slower rates than through the aquifer.

Two basic factors determine the degree of vulnerability of the aquifer system to surface contamination: the type of aquifers in the system, and the extent of inter-connection between them. There are three general types of aquifers: unconfined, confined, and semi-confined. One extreme is the unconfined aquifer, which has as its upper confining surface the watertable. It is the most vulnerable aquifer to surface contamination. The other extreme is the confined aquifer where two aquitards or aquicludes are the upper and lower boundaries. An intermediate type is a semi-confined aquifer which permits some flow exchange through aquitards and between two aquifers.

**2.2.3.0 Hydrologic Properties of Aquifer Materials.**  
Aquifers have been defined as geologic deposits with

sufficient ground water saturation, void spaces, and adequate hydraulic transmissivity to produce a sustained discharge of water to wells or natural springs. The ability of a geologic

deposit to store and transmit water is a function several specific properties, such as:

(1) Flow Spaces:

Void Spaces - The void spaces in geologic materials determine the storage, flow, and transport characteristics of the aquifer system. There are two types of void spaces:

A. Intergranular flow spaces - Intergranular flow spaces are found between the particles of a granular medium such as gravels, sands and silts or mixtures thereof. These flowspaces, in general, are more uniformly distributed throughout the unit.

B. Channelized flow spaces - the flow spaces exist as fractures, joints and other planes of separation (bedding planes) or solution channels. Here, flow is more localized and confined to the individual flow channels but with relatively higher flow velocities.

Combinations of both types of flow spaces exist where joints or fractures dissect consolidated or competent unconsolidated materials, thus forming channels with high flow velocities around blocks through which transport occurs at much lower rates through the pores.

Porosity - Porosity is the property of a geologic material to contain and store fluids. It is the ratio of the volume of the pore or flow spaces to the total rock volume. Effective porosity is the fraction of void spaces that are effectively interconnected and actively participate in fluid transmission.

(2) Interconnection of Flow Spaces:

Even though an aquifer may have a large percentage of void spaces and could potentially store a large volume of water, the aquifer may not be very effective at transmitting water. The ability of an



aquifer to transmit water, therefore, is also a function of the size and shape of these flow spaces and their degree of interconnection.

Intrinsic Permeability - Intrinsic permeability is the property of a porous medium to transmit fluids, and is independent of the nature of the fluid or the potential field. It has dimensions of a length squared which in a sense is analogous to the area of a flow channel. Values range from  $10^{-13}$  m<sup>2</sup> for tight materials to  $10^{-6}$  m<sup>2</sup> for more permeable materials.

Hydraulic Conductivity - Hydraulic conductivity expresses the capacity of a porous medium to conduct or transmit fluids. The hydraulic conductivity is numerically equivalent to the discharge that will flow through a unit area of aquifer material under a unit head gradient. Its accepted dimensions are length over time, and the range of values for different geologic materials ranges from  $10^{-2}$  m/sec for very permeable materials to  $10^{-10}$  cm/sec for very tight materials. Hydraulic conductivity embodies properties of the porous medium as well as those of the flowing water. Specifically, its density and viscosity. However, the specific intensive properties alone do not give an idea about the hydraulic performance of the entire system.

Storativity and Transmissivity - The extensive aquifer properties are storativity and transmissivity. Storativity is defined as the amount of groundwater that will be released from a column of material with unit base extending through and the entire thickness of the aquifer under unit head reduction. Transmissivity defines the total discharge that can be obtained from a unit width of the entire saturated thickness of an aquifer under a unit head gradient. Transmissivity is the product of hydraulic conductivity and aquifer thickness.

The above text discusses the relationship between two specific properties of aquifers (flow spaces and interconnection of the flow system) and the ability of an aquifer to store and transmit water. The basic role of an aquifer system in the transport of contaminants, however, is twofold. Not only does

the aquifer have the capability to store and transmit fluids; but, the aquifer also provides the opportunity for mixing and reaction between the pore fluids and the aquifer-matrix.

2.2.4.0 Geologic and Hydrologic Characteristics of Formations Underlying the St. Louis Park Area

The following description of the different geologic units underlying the St. Louis Park area combines geologic features and hydrologic characteristics discussed earlier. The descriptions proceed from the deepest aquifer unit, the Mt. Simon-Hinckley, to the uppermost glacial drift aquifer. Aquitards are also discussed because they are important to understanding of a coherent system.

The description is given in a unified and tabular form. A map of the bedrock units is shown on figure \_\_\_\_.

Mount Simon - Hinckley Aquifer

- Geologic characteristics: Sandstone, grayish-white to pink, silty to coarse grained, well cemented, quartzose; parts are medium-to coarse-grained, well sorted.
- Approximate range of thickness: Up to 260-270 feet.
- Areal extent: Underlies the entire study area.
- Water bearing characteristics: Porosity is intergranular high transmissivity. Generally discharges more than 1,000 gal/min to high-capacity wells.
- Use: Supplies about 15 percent of ground water pumped in the St. Louis Park and seven-county metropolitan area.

Eau Claire Confining Bed

- Geologic characteristics: Siltstone and shale, green, glauconitic.
- Approximate range of thickness: Up to 105 feet.
- Areal extent: Underlies the entire study area.
- Water bearing characteristics: Confining bed; hydraulic characteristics poorly known.
- Use: The Eau Claire confining bed is an aquitard; therefore, there are not water supply wells in the unit.

Ironton - Galesville Aquifer

- Geologic characteristics: Sandstone, white to light green, moderately well sorted, fine to coarse grained, quartzose.
- Approximate range of thickness: Up to 50 feet.
- Areal extent: Underlies the entire study area.
- Water bearing characteristics: Porosity is intergranular; low transmissivity.
- Use: Regionally an aquifer, but no wells are known to yield water exclusively from this unit in the study area.

St. Lawrence - Franconia Confining Bed

- Geologic characteristics: Siltstone and sandstone, gray to green, poorly sorted, glauconitic and dolomitic.
- Approximate range of thickness: 150-250 feet.
- Areal extent: Underlies the entire study area.
- Water bearing characteristics: Confining bed, hydraulic characteristics poorly known.
- Use: The St. Lawrence - Franconia confining bed is an aquitard; therefore, there are no water supply wells in this unit.

Prairie du Chien - Jordan Aquifer

**Geologic Characteristics:**

Prairie du Chien Group - Dolomite, sandstone, sandy dolomite, light brown, buff, gray, thinly to thickly bedded.

Jordan Sandstone - Sandstone, white to pink, fine to coarse-grained moderately well cemented, quartzose to dolomitic.

**Approximate range of thickness:**

Prairie du Chien Group - 0-170 feet

Jordan Sandstone - 0-130 feet

**Areal Extent:**

Prairie du Chien Group - Absent in north and west parts of study area. Locally absent due to erosion.

Jordan Sandstone - Absent in extreme west and northern parts of study area.

**Water bearing characteristics:**

Prairie du Chien Group - Generally yields more than 1,000 gal/min to high capacity wells. Hydraulic conductivity is due to fractures, open joints, and solution channels.

Jordan Sandstone - Hydraulic conductivity is mostly intergranular but may be due to joint parting in cemented areas. Prairie du Chien-Jordan aquifer generally yields more than 1,000 gal/min to high capacity wells.

Use: The Prairie du Chien - Jordan aquifer not only supplies about 80 percent of the groundwater pumped in the study area; but, the aquifer also provides approximately 75 percent of the annual groundwater supply in the Twin Cities.

Basal St. Peter Confining bed

Geologic Characteristics: Siltstone and claystone, red, green, and white; parts are plastic in texture and poorly indurated; interbedded with fine-grained quartz sandstone.

Approximate range of thickness: 0-65 feet.

Areal extent: Generally present over most of the central part of the study area. Locally absent due to erosion.

Water bearing characteristics: Hydraulic conductivity is highly variable; siltstone and claystone restrict vertical flow but sandstone discharges as much as 100 gal/min to wells.

Use: As a whole, the Basal St. Peter confining bed is an aquitard. No wells are known to yield water only from this unit in the study area.

St. Peter Aquifer

Geologic characteristics: Sandstone, white to yellow, very well sorted, fine-to medium-grained, poorly cemented, quartzose.

Approximate range of thickness: 0-100 feet.

Areal extent: Generally present over most of the study area. Locally absent due to erosion.

Water bearing characteristics: Porosity approximately 30%; can discharge more than 500 gal/min. to wells. Sandstone is poorly cemented and wells tend to pump sand or fill in.

Use: Supplies about 10 percent of ground water pumped in the St. Louis Park area. Most wells completed in the sandstone are of small diameter and used for domestic supply.

#### Glenwood Confining Bed

Geologic characteristics: Shale and claystone, green to buff, plastic to slightly fissil, lower 3 to 5 feet grade from claystone with disseminated sand grains to sandstone with clay matrix.

Approximate range of thickness: 0-18 feet.

Areal extent: Present only in central part of study area. Dissected by erosion.

Water bearing characteristics: Very low hydraulic conductivity, Vertical hydraulic conductivity is estimated to be about  $10^{-10}$  ft/s based on laboratory measurements of core samples.

Use: The Glenwood confining bed is an aquitard. Therefore, there are no water supply wells in this unit.

Platteville Aquifer

- Geologic characteristics: Dolomitic limestone and dolomite, gray to buff, thin to medium bedded, some shale partings. Solution channels and fractures are concentrated in upper part and contain sand and gravel of glacial origin.
- Approximate range of thickness: 0-35 feet.
- Areal extent: Present only in central part of study area. Dissected by erosion.
- Water bearing characteristics: Hydraulic conductivity primarily from fractures, open joints, and solution channels. Specific capacities of wells are generally between 10 and 100 (gal/min)/ft of drawdown, if pumped at about 12 gal/min for 1 hour. Results from one aquifer test indicates that the transmissivity of the unit is about 9,000 ft<sup>2</sup>/d near the test site.
- Use: The Platteville aquifer is a lower-capacity commercialized industrial water supply.

Decorah Shale Confining Bed

- Geologic characteristics: Shale, blueish-green to blueish-gray, blocky.
- Approximate range of thickness: 0-95 feet.
- Areal extent: Locally present in east.
- Water bearing characteristics: Confining bed.
- Use: The Decorah Shale confining bed is an aquitard; therefore, there are no water supply wells in this unit.



Glacial Drift Aquifer

- Geologic characteristics: Undifferentiated over most of the study area. Till, outwash and valley-train sand and gravel, lake deposits and alluvium; vertical and horizontal distribution of units is complex. Units have been differentiated in the immediate area of the plant site. These units include a poorly-defined (unconfined) Upper Drift aquifer, a Middle Drift aquifer, and a lower-drift complex.
- Approximate range of thickness: 50-400 feet.
- Areal extent: Underlies the entire study area; however, the distribution of aquifers and confining beds within the drift is poorly known outside the area of the plant site.
- Water bearing characteristics: Stratified well-sorted deposits of sand and gravel yield moderate to large supplies of water to wells (240-2,000 gal/min). Results from one aquifer test indicates that the transmissivity of the Middle Drift aquifer near the plant site is about 9,000 ft<sup>2</sup>/d (Hult, in preparation).
- Use: The Glacial Drift aquifer was a source of water supply, both domestic and commercial.

2.3.0.0 General Groundwater Flow Mechanics.

2.3.1.0 Water Levels, Potentiometric Surfaces, and Regional Groundwater Flow

Water levels measured in wells are the only observable manifestation of groundwater hydraulics. From these water levels, two basic features can be derived:

- (1) The potentiometric surface, which is an interpolated surface constructed very much like a topographic surface on a map. The surface is contoured with lines of equal head or equipotential. The potentiometric surface defines the level to which groundwater would rise at a given location if a well were installed at that point. (The water table is a special potentiometric surface as it represents the physical upper surface of an unconfined aquifer.)
- (2) Well hydrographs, which are plots of water level change in one well with time. They give information about the fluctuation of potentiometric surfaces and their correlation with driving processes such as recharge or artificial pumping stresses.

Ground water flows perpendicular to equal head or equipotential lines; from high to low potential. In general an aquifer has its highest potential at the recharge area and its lowest at the discharge area. All groundwater systems are basically driven by recharge - discharge relationships across the system. The regional flow pattern for the aquifer system also depends on the configuration of the potential surface throughout the aquifer and the hydraulic characteristics of the aquifer.

In the St. Louis Park area potentiometric surfaces have been constructed on the basis of well information for each of the aquifer systems. It shows that the elevation of the potential surfaces are successively lowered as one goes from the highest aquifer system, the Drift, to the lowest, the Mt. Simon - Hinckley. This means that if an appropriate pathway, natural or artificial, can be found, groundwater would move downward.

The general slope of all potentiometric surfaces of the aquifers in the St. Louis Park area are similar. The contour lines connecting points of equal potentiometric head all trend in a northerly direction. The slope of these potentiometric surfaces are gradual from the west towards the east which means that the regional groundwater flow is in this direction. The Lake Minnetonka area seems to function as a recharge area, with the Mississippi River acting as the principal ground water discharge area. In the St. Louis Park area, lines connecting equal potentiometric heads are bent in the southern part of the larger region where the Minnesota River also acts as a discharge boundary line.

#### 2.3.2.0 Flow Equations

In order to solve any particular groundwater flow problem it is necessary to first formulate the general flow equations.

These are obtained by manipulating and combining three basic mathematical statements: the principle of mass conservation applied to groundwater flow, Darcy's equation for groundwater flow, and the equation of state which describes changes caused by pressure and temperature.

In the end, all groundwater flow situations can be expressed by a handful of equations. Some of these equations are of great complexity. However, they form the basis for computer modeling where the differential equations are approximately solved by numerical methods.

#### 2.3.3.0 Vertical Flow and Leakage

In multiple aquifer systems, separated by aquitards,

interaquifer flow can occur. Several factors control the effectiveness of an aquitard:

- (1) The magnitude of the hydraulic conductivity of the aquitard plays an important role in vertical flow and leakage.
- (2) The magnitude and direction of the hydraulic head difference between upper and lower aquifers. As discussed earlier, groundwater flows from higher potential head to lower potential head. If the magnitude of the head difference between the aquifer is large, leakage may be induced across the aquitard unit separating the two aquifers.

- (3) The thickness of the aquitard. The vertical travel times of leakage from one aquifer to another is directly proportional to the aquitard thickness.

For the St. Louis Park area, as a consequence of glacial erosion, there are places where an aquitard may be thin or is virtually absent. This situation creates a natural connection between aquifers. A buried bedrock valley can be found 1.5 miles east to southeast of the Reilly site. This buried bedrock valley not only permits a natural hydraulic connection between the drift and Platteville aquifers; but, also permits a hydraulic connection between the Drift and the St. Peter aquifers.

Multiaquifer wells are wells open to two or more aquifers. They include wells that may be improperly cased and/or abandoned. This condition provides a convenient pathway for the groundwater of one aquifer to flow to a different aquifer.

Numerous multiaquifer wells have been known to exist in the St. Louis Park area. Many of these wells were constructed to supply water to developing industry at the turn of the century. Their condition has deteriorated over the years.

#### 2.4.0.0 General Groundwater Chemistry

The hydrologic process brings groundwater into contact with the earth materials that make up the aquifer. Reactions occurring between the water and the earth materials give a characteristic hydrogeochemical imprint. As a basis for understanding contaminant behavior in an aquifer system, an understanding of the natural chemistry of groundwater is necessary.

#### 2.4.1.0 Natural Constituents in Groundwater.

Groundwater interacts chemically with the aquifer matrix material under natural circumstances and becomes a weak electrolyte solution. Anthropogenically introduced inorganic and organic constituents dissolve in varying degrees into groundwater and attain a high degree of mobility in the dissolved form. The different hydrologic and physicochemical processes in the aquifer discussed below can greatly modify the contaminants mobility and concentration as they are transported through the aquifer.

When water is sampled for analytical purposes several bulk parameters are measured at the well site. These parameters are electrical conductance, temperature, pH and Eh. The most common is specific electrical conductance, usually given in micromhos or micro simens. Electrolyte conductivity is a

direct measure for the amount of ions in solution, the larger the ion concentration the higher the conductivity. Simple rules of thumb equate the total amount of dissolved solids in milligram per liter to the specific conductivity in micromhos multiplied by a factor of 0.65 to 0.70. Total dissolved solids (mg/l) are obtained by evaporation of the water sample and weighing the residue. This measure includes all dissolved solids, not only those that contribute to electrical conductivity.

Descriptors of the environmental condition of the groundwater sample include temperature, pH or acidity, and Eh or redox potential. These parameters indicate the stability of different mineral and ionic solutions and they can serve to identify the chemical environment of ground waters.

From a chemical point of view it is useful to divide the constituents into inorganic (or ionic) and organic components.

**2.4.1.1 Inorganic Constituents:** The most common process of dissolving chemical species into groundwater is by direct dissolution of a mineral into water. Dissolution of table salt (sodium chloride) is an example. In water, the sodium and chloride are dissolved separate but the dissolution reaction can reverse and the element can combine and precepitate out as salt again.

Groundwater chemical constituents are usually presented in three groups: major ions, minor elements and trace elements. The major ion group contains a relatively small number of chemical species that dissolve into water. Therefore, we classify water chemistry on the bases of greatest quantity of anion and cations present. The major anion (negatively charged ions) groups are bicarbonate ion, sulfate ion and chloride ions. The corresponding major cations (positively charged ions) are the sodium-potassium group, calcium ion, and magnesium ion. Most of the natural waters in the St. Louis Park area are of the bicarbonate-calcium-magnesium type, which is typical for water derived from drift and bedrock materials of the kind found in St. Louis Park. Minor elements are iron, manganese, fluoride and others. Their concentrations are at  $10^2$  micrograms per liter (ug/l) levels. Trace elements are certain metals much as copper, chromium, cadmium. They occur in the ug/l range.

Table \_\_ gives a summary overview of major, minor and trace elements in groundwater.



2.4.1.2 Organic Constituents: Groundwaters may have some natural organic constituents. In most cases these are organic acids, humic substances and other organic compounds associated with wetland and peat deposits. In multiple glaciated terrains, soils and organic deposits are formed during interglacial periods. Later glacial advances may subsequently bury them. The trapped organic materials then may act as a source for dissolved organics in the groundwater. Bulk indicators for organic materials are total organic carbon (TOC), dissolved organic carbon (DOC) and biological oxygen demand (BOD); the latter most often used as an indicator of contamination by general organic wastes.

The presence of inorganic compounds in groundwater regulates, to a certain extent the environmental conditions such as acidity, pH, and state of oxidation or redox potential Eh. Therefore, they have a great influence on the solubility, partition coefficients and absorption coefficients of dissolved organics. Their presence, in addition to the presence of nutrient phosphorous and nitrogen compounds (usually introduced through surface contamination) determines the bacterial environment in which biodegradation processes take place.

2.4.1.3. Measure of Concentration: Analyses are commonly given as mass per volume concentrations - g/l, kg/m<sup>3</sup>, mg/l or as ratios: parts per million (ppm), parts per billion (ppb), etc., or mg/kg, ug/kg. At low concentrations, mg/l, mg/kg, ppb are interchangeable, but this is not so at higher concentrations, in the g/kg range for example.

2.4.2.0 Coal Tar Derived Contaminants and the St. Louis Park Groundwater Problem

This section on coal tar derivatives and the St. Louis Park groundwater contamination problem focuses on:

- (1) First, the general aspects of a contaminant source after it has been introduced into the groundwater system.
- (2) The type of contamination that can be expected in urbanized areas.
- (3) The description of potential sources of coal tar derived contaminants from the St. Louis Park site.

2.4.2.1. Contaminant Introduction to the Groundwater System:

The types of contaminants introduced into the groundwater system at the coal tar plant were organic compounds. These compounds are derivatives of coal tar and fall in the classification commonly referred to as hydrocarbons. Hydrocarbon compounds have extremely low solubilities in water. The solubility of a contaminant compound in any groundwater contamination problem is a very important aspect to the solution of the problem. Highly soluble materials such as road salts

or entirely miscible liquids such as alcohol or phenols result in single phase flow and miscible displacement. Very sparingly soluble materials such as creosote oils, tar products, and other hydrocarbons form separate fluid phase regions. Therefore, the significance of the introduction of hydrocarbon contaminants into groundwater systems is the establishment of multiphase flow regimes. The contaminants do not readily disperse; but rather form an infiltration body which remains relatively immobile.

This infiltration body acts as the source of contamination by the dissolved hydrocarbon compounds found in the groundwater. Since the infiltration body is practically immobile after initial emplacement, its persistence over time is very long, whereas its areal and volumetric extension may be relatively small. The dissolved hydrocarbons move with the groundwater flow and are, therefore, the most mobile part of the pollutant emanating from the source.

The magnitude of capillary and interfacial phenomena between the contaminant and the groundwater is a very important factor in determining the area and shape of any contaminant body. However, there are four other factors which are also significant in determining the area and shape of contaminant bodies:

- (1) The conditions under which the contaminant is introduced into the subsurface.
- (2) The aquifer properties.
- (3) The subsequent history of infiltration-recharge events.
- (4) Artificial stresses such as pumping in the vicinity of the source also influence its shape.

2.4.2.2. Contaminants in Urbanized Areas: A common problem of tracing the source of organic contaminants in a heavily industrialized, or urbanized region is the large number of other contaminants that potentially can be introduced into the environment. These substances range from household and commercial solvents to industrial solvents, fuel oil, gasoline, diesel fuel and dry cleaning solvent, to mention a few. Pollutants in the soils, subsurface and groundwater under urbanized areas are either directly linked to well defined activities or are the result of accidental releases. An example of the first group is high concentrations of dissolved salts in subsurface materials from road salting. On the other hand, accidental sources of contamination may include spills from leaks or tank ruptures.

There is the potential for many forms of contamination in urbanized areas. It is important to note, however, because of the unique origin of coal tar derivatives, that coal tar derivatives can usually be distinguished from other urban

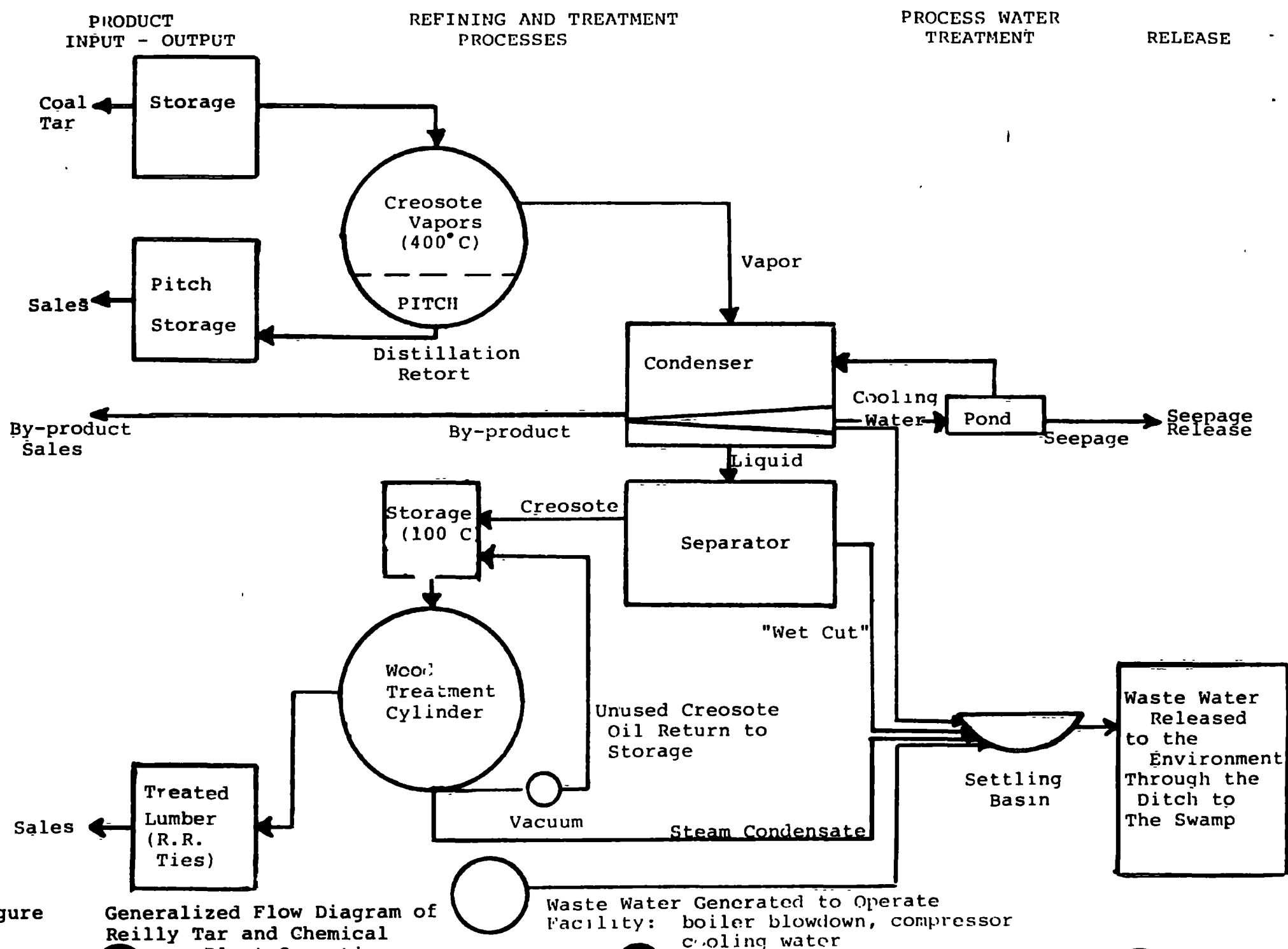


Figure Generalized Flow Diagram of Reilly Tar and Chemical Company Plant Operations, Louis Park, MN.

contaminants and sources. Coal tar distillation products, especially the creosote fraction, has a characteristic chromatographic signature which makes it distinguishable from other urban contaminants.

2.4.2.3. Contamination Sources -- Coal Tar Derivatives:

Most of the contaminants found on the Reilly Tar and Chemical site are coal tar derivatives such as phenolics and PAH's. This is to be expected from the past land use of the site as a coal tar distillation plant and wood treatment facility.

Although the Reilly Tar Company plant operations are described in much greater detail in other documents, a very simple schematic of the operations in the form of a flow diagram is given in figure \_\_. The figure identifies the waste-contaminant output from the facility and identifies different possible sources for surface-water-groundwater contamination.

The following possibilities for contaminant entry into the subsurface exist:

- (1) Drainage of wastewater generated by contact and non-contact processes that are part of the refinery and wood treatment operation.
- (2) Major spillage due to tank failure, accidental overflows.
- (3) Chronic spillage from leaky pipes and valves, drippings from stored wood products

- (4) Seepage from waste water disposal system and sludge disposal sites.
- (5) Washoff from stored, treated railroad ties in the yard during rainstorms.
- (6) Surface runoff flowing through the site and picking up contaminant from surface depressions, etc.
- (7) Introduction of dissolved or free phase creosote products into the groundwater reservoir by way of abandoned wells or along the outside casing of poorly installed wells, or through wells open to several aquifers.

Geographically the major source areas for contamination are:

- (1) Spill impregnated subsurface of the plant site itself.
- (2) Surface depressions south of the site, specifically the swamp area around well W13.
- (3) Multi-aquifer wells open to spillage or disposal, especially Republic Deep Well (W23).

#### 2.5.0.0 Contaminant Transport in Aquifers.

In keeping with the analog mentioned at the beginning of this report, the aquifer system is the transmitter of the contaminant. At the same time the aquifer constantly interacts with the water, changing the contaminant concentration and constitution.

In the aquifer system other changes in concentration can be introduced through dilution by infiltration, additional pollution by cross contamination from other aquifers or by introduction of unreported or unrecognized spills.

### Driving Mechanism and Flow Pattern

Groundwater flow in an aquifer system results from a discharge across the aquifer medium produced by a head or water level difference over the distance considered. All groundwater systems are basically driven by recharge - discharge relationships across the boundaries of the system. The local flow path and the resulting overall flow pattern for the aquifer system depend on the geometry of the container, the configuration of the potential surface or head distribution throughout the aquifer and the hydraulic characteristics of the aquifer such as storativity and transmissivity. Water flows in response to the potential gradient or head distribution according to Darcy's equation: Discharge is equal to the product of the area normal to flow and the hydraulic gradient and a proportionality constant which is the hydraulic conductivity.

#### 2.320 Flow Equations

In order to solve any particular groundwater flow problem it is necessary to first formulate the general flow equations. These are obtained by manipulating and combining three basic mathematical statements. The first is an expression of the principle of mass conservation applied to groundwater flow, the second is a force-flux relationship which indicates how groundwater flows under



application of a generalized force (Darcy's equation), and the last is an equation of state which describes how the pore fluids and the solid matrix skeleton behave when pressure and temperature changes occur.

Given a set of simplifying assumptions about the elasticity or incompressibility of the aquifer, constancy of temperature and linear flow laws, the governing equations can be written. As it turns out, these are partial differential equations for which general solution methods need to be found before a particular groundwater problem can be solved. Depending on the real conditions and assumptions made, solutions exist for general classes of problems and conditions. Steady state conditions and incompressible homogeneous and isotropic systems give rise to a partial differential equation called the Laplace equation. The same conditions combined with steady recharge result in the Poisson equation.

Compressible and elastic conditions lead to an unsteady state or transient equation, also called the diffusion equation.

The point to be made here is that all groundwater flow situations can be expressed by a handful of equations, some of which admittedly are of great complexity. They

all, however, form the basis for computer modeling where the differential equations are approximately solved by numerical methods.

Any particular solution for a given groundwater flow problem has to use the geometry of the flow field and the conditions of flow at the boundary. These boundary conditions may specify inflow or outflow, head conditions, or impermeability over parts of the boundary geometry. When the particular solution satisfies the conditions on the boundary and within the field, the problem is solved.

#### 2.330 Control of Potential Surface and Regional Flow Direction

The solution most often specifies a potential surface from which flow directions and flow velocities at each point in the field or in the model grid space can be calculated and plotted.

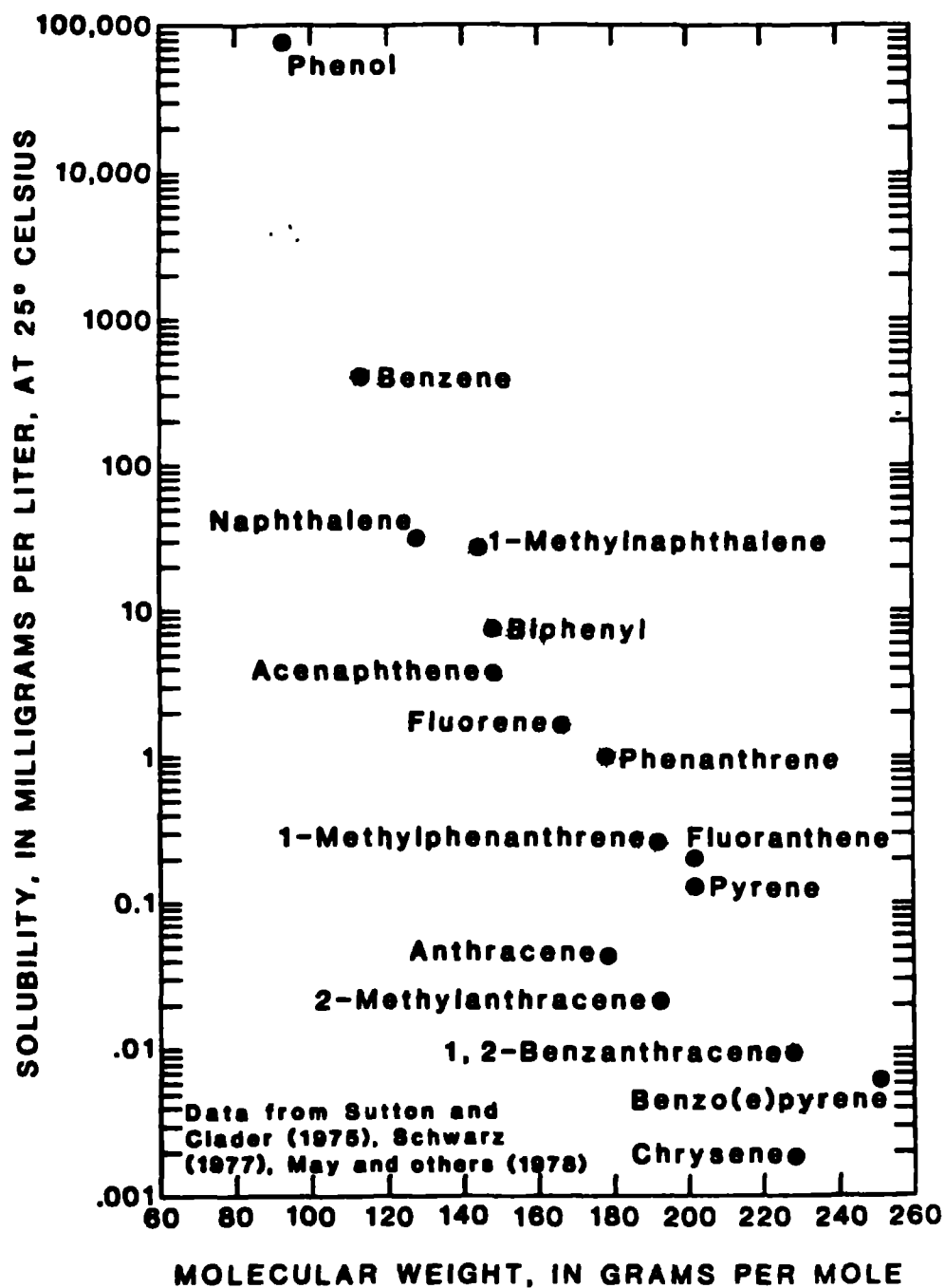
The shape and morphology of the potential surface in an aquifer reflects both the regional or large scale trends in flow as well as local variations caused by variability in the aquifer geometry or hydraulic parameters. For confined aquifers the potential surface is fictitious in that it defines the level to which water would rise if a well had been installed at that point. By necessity, the surface has to be constructed by interpolation of

Figures A, B, and C

Show General Trends

Of Hydrocarbon Characteristics

As A Function Of Molecular Weight



**FIGURE**      **RELATIONSHIP BETWEEN SOLUBILITY AND MOLECULAR WEIGHT FOR SELECTED COAL-TAR COMPOUNDS (M.F. HULT AND M.E. SCHOENBERG, U.S. GEOLOGICAL SURVEY WATER-SUPPLY PAPER 2211).**

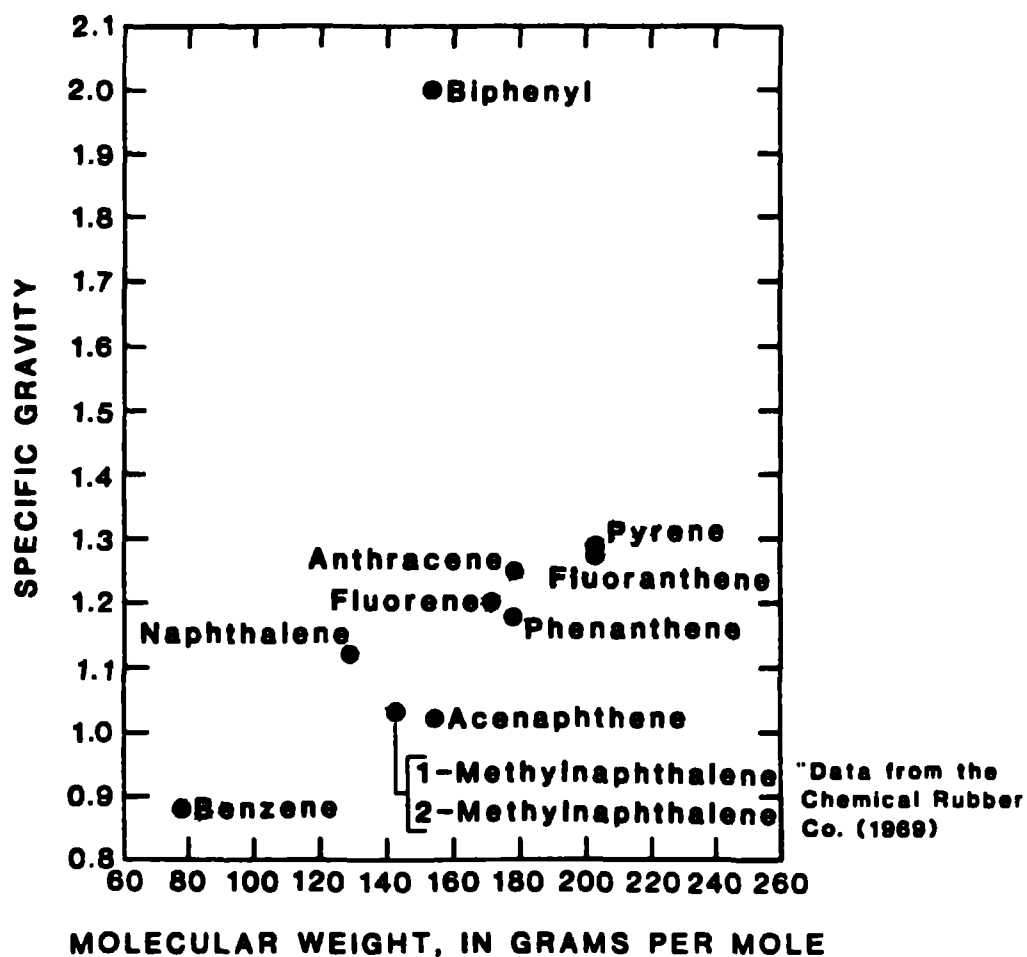
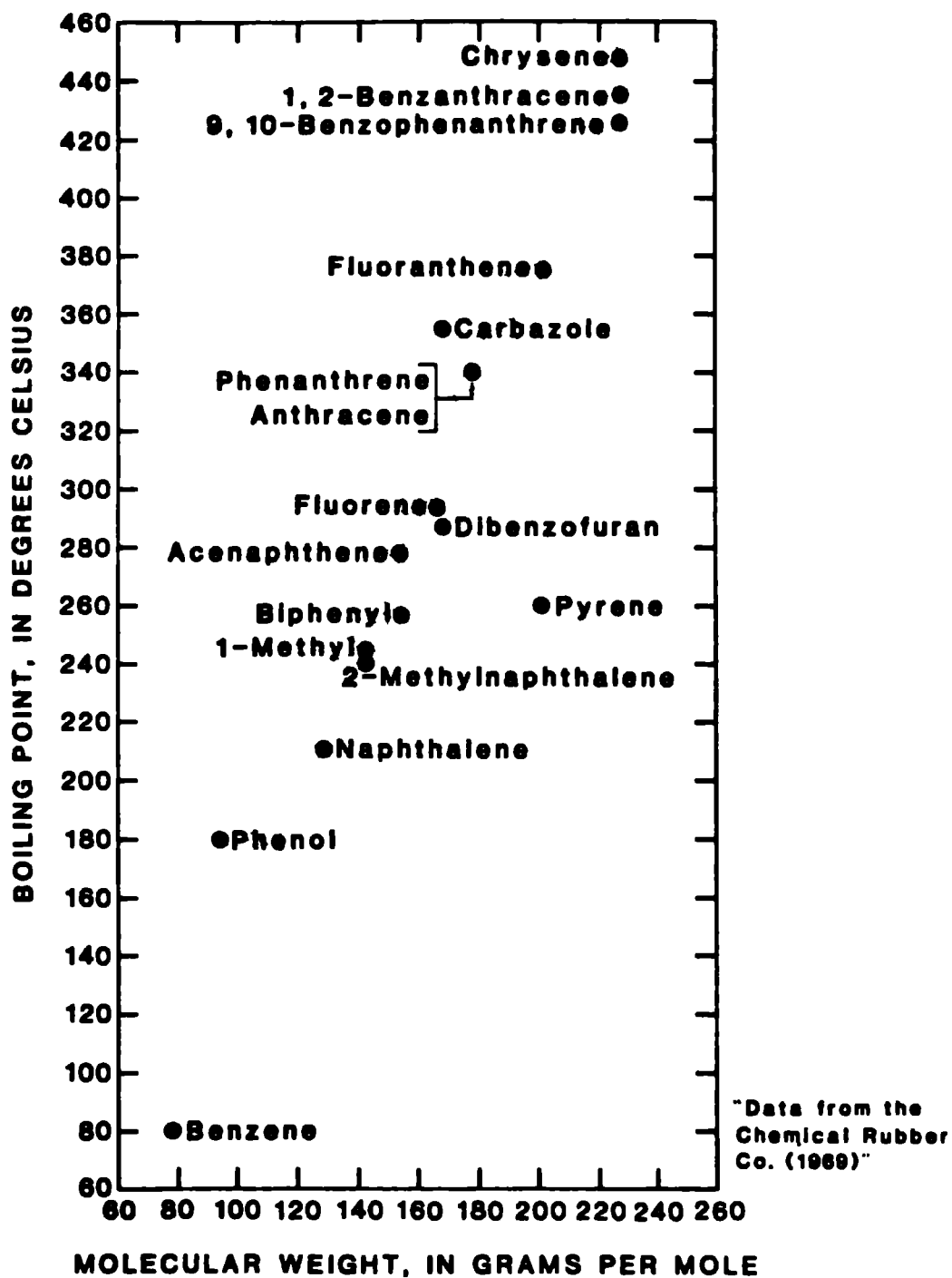


FIGURE RELATIONSHIP BETWEEN SPECIFIC GRAVITY AND MOLECULAR WEIGHT FOR SELECTED COAL-TAR COMPOUNDS (M.F. HULT AND M.E. SCHOENBERG, U.S. GEOLOGICAL SURVEY WATER-SUPPLY PAPER 2211).



**FIGURE** RELATIONSHIP BETWEEN BOILING POINT AND MOLECULAR WEIGHT FOR SELECTED COAL-TAR COMPOUNDS (M.F. HULT AND M.E. SCHOENBERG, U.S. GEOLOGICAL SURVEY WATER-SUPPLY PAPER 2211).

lines of equal head between existing wells. The water table is a real potential surface, in that it represents the upper limit of the free groundwater body in direct contact with the free soil atmosphere. Unlike fixed, confined beds, the position of the water table may fluctuate in time and with transient stresses on the system. Groundwater flow velocities are determined either by field observation and reconstruction of the potential surface or by applying computer methods. The first approximation in treating contaminant transport links mass transport directly to flow velocities by a simple displacement or advection process. But, also for more sophisticated cases, where dispersion and mass exchange is considered, it is the groundwater flow velocity that greatly influences dispersion and mass transfer coefficients.

#### 2.340 Vertical Flow and Leakage

In multiple aquifer systems, separated by aquitards, interaquifer flow or vertical leakage can occur. It depends on the hydraulic conductivity in the aquitard, its thickness and the magnitude and direction of head difference between the two adjoining aquifers. Depending on the magnitude of these factors, actual leakage under normal conditions may be minimal except when artificial connections are created by multiaquifer wells or by improperly sealed and isolated abandoned wells.

For Ground Water Outline — Section I (Intro)

Fig. St. Louis Park Aquifer Characteristics Summary

Aquifer	Composition	Porosity	Flow Velocities/ Directions	Pumping Stresses <sup>1</sup>	Dispersion	Sorption <sup>2</sup>	Biodegradation
Drift	sand and gravel	intergranular high	slow/ southeast	negligible	medium	likely	possible
Platteville	limestone	fracture low	medium/ south and east	minor	important	negligible	minor
St. Peter	sandstone	intergranular high	slow/ southeast	minor	medium	likely	minor
Prairie du Chien	dolomite	fracture low	fast/ multidirectional (due to pumping)	important	high	negligible	minor
Jordan	sandstone	intergranular high and fracture	slow/ multidirectional (due to pumping)	important	medium	likely	minor
Ironton-Galesville	sandstone	intergranular high	slow/ southeast(?)	negligible	medium	likely	minor
Mt. Simon - Hindley	sandstone	intergranular high	slow/ multidirectional (due to pumping)	important	low	likely	minor

1. Importance of pumping stresses on ground water flow rate and direction.

2. Significance of sorption on rate of contaminant movement.

3. Dependence on oxygen availability



2.400 General Groundwater Chemistry

The hydrologic processes bring groundwater into contact with the geologic - mineralogic materials of an aquifer system. The resulting reactions give a characteristic hydrogeochemical imprint to the groundwater. The basis for understanding contaminant behavior in an aquifer system is the proper assessment of the natural chemistry of groundwater. It serves as a baseline from which deviations can be measured and it serves as a point of departure from where the effects of chemical stresses can be estimated by extrapolation from the natural system.

2.410 Natural Constituents in Groundwater.

Groundwater interacts chemically with the aquifer matrix material under natural circumstances and becomes a generally weak electrolyte solution. Anthropogenically introduced inorganic and organic constituents will dissolve totally or partially into groundwater and attain a high degree of mobility in the dissolved form. The different hydrologic and physicochemical processes in the aquifer discussed below can greatly modify their mobility and levels.

From a chemical point of view it is useful to divide the constituents into inorganic - ionic and organic components.

2.420 Inorganic Constituents: The most prevalent form of acquiring chemical species into groundwater is by direct dissolution reactions from the mineral substance or as soluble reaction products from mineral weathering processes. Dissolution of calcium carbonate from limestone is an example of the first, production of potassium or sodium ions from feldspar weathering an example of the second.

Groundwater constituents are usually presented in three groups: major ions, minor elements and trace elements. The major anion groups are bicarbonate ion, sulfate ion and chloride ions. These so-called independent ions are

used to classify natural groundwater chemistry. The corresponding major cations are the sodium-potassium group, calcium ion, and magnesium ion. Most of the natural waters in the St. Louis Park area are of the bicarbonate - calcium-magnesium type, which is typical for water derived from drift and bedrock materials of the kind found in St. Louis Park. Minor elements are iron, manganese, fluoride and others. Their concentrations are at  $10^2$  ug/l levels. Trace elements are certain metals such as copper, chromium, cadmium. They occur in the ug/l range.

Besides the specified chemical constituent of groundwater a number of other bulk parameters are used to characterize its quality. The most current is specific electrical conductance, usually given in micromhos or microsimens. Electrolyte conductivity is a direct measure for the amount of ions in solution, the larger the ion concentration the higher the conductivity. Simple rules of thumb equate the total amount of dissolved solids in milligram per liter to the specific conductivity in micromhos multiplied by a factor of 0.65 to 0.70. Total dissolved solids (mg/l) are obtained by evaporation of the water sample and weighing the residue. This measure includes all dissolved solids, not only those that contribute to electrical conductivity.

Descriptors of the environmental condition of the ground-water sample include temperature, pH or acidity, and Eh or redox potential. These parameters indicate the stability of different mineral and ionic solutions and they can serve to identify the provenance of ground waters. Table 1 gives a summary overview of major minor and those elements in groundwater.

2.430 Organic Constituents: Groundwaters may have some natural organic constituents. In most cases these are organic acids, humic substances and other organic compounds associated with wetland and peat deposits. In multiple glaciated terrains soils and organic deposits are formed during interglacial periods. Later glacial advances may subsequently bury them. The trapped organic materials then may act as a source for dissolved organics in the groundwater. Bulk indicators for organic materials are total organic carbon (TOC), dissolved organic carbon (DOC) and biological oxygen demand (BOD); the latter most often used as an indicator of contamination by general organic wastes. Analyses are most commonly given as mass per volume concentrations - g/l, kg/m<sup>3</sup>, mg/l or as ratios: parts per million (ppm), billion (ppb), etc., or mg/kg, ug/kg. At low concentrations, mg/l, mg/kg, ppb are interchangeable, but not so at higher concentrations, in the g/kg range for example.

The presence of inorganic compounds in groundwater regulates, to a certain extent the environmental conditions

such as acidity, pH, and state of oxidation or redox potential Eh. Therefore, they have a great influence on the solubility, partition coefficients and absorption coefficients of dissolved organics. This, in addition to the presence of nutrient phosphorous and nitrogen compounds, (usually introduced through surface contamination) determines the bacterial environment in which biodegradation processes take place.

#### 2.500 Contaminant Emplacement.

This section focuses on the general aspects of a contaminant source after emplacement, the general contaminant situation in urban areas and the description of potential sources of hydrocarbon contaminants from the St. Louis Park site.

The most important factor in contamination cases where lipophilic organic materials with extremely low solubility in water infiltrate and percolate through geologic material is the establishment of a multiphase flow regime. This results in the formation of an infiltration body by the organic phase which remains relatively immobile. It forms the source of contamination by dissolved constituents. Because of its low mobility its persistence over time is extensive, whereas its areal and volumetric extension is relatively small. The dissolved constituents move with the groundwater flow and are, therefore, the most mobile part of the pollutant emanating

PROCESSES	SOURCE	TRANSMITTER	RECEIVER/DETECTOR
	Contaminant Body	Aquifer System	Wells
Physico-Chemical-Mass Transfer	Source Strength Controls: Solubilities Exchange Area & Volume Mass Transfer Coefficient Capillary and inter-facial forces  Environmental factors: T, pH, Eh	Sorption Phenomena Chemical Reaction Ex-solution-2 phase fluids	Phase separation (change of environmental condition) Evaporation loss of volatiles Adsorption to screen and casing
Hydrologic: flowfield	flow velocity contact opportunities	Advection - Dilution Dispersion	Alteration (dilution) of flow field by pumping (sampling)
Watertable fluctuation	Increase of specific exchange area (trapped globules) rejuvenation of exchange surfaces Vertical contact and entrainment of contaminant	Inhomogeneous flow field: differential arrival times	Location of detector: is plume intercepted?
Biologic Bacterial Action	Availability of Oxygen, Carbon, Nutrients Absence of Toxins Environmental Condition: T, pH	Oxygen transport by recharge, displacement, diffusion Nutrient input: Land Use	Perturbation by O <sub>2</sub> introduction, through presence of well
Artifacts - Interferences		Undocumented spills Background interferences	Errors in sampling, handling and storage

Table \_\_ Summary of processes affecting source - transmitter - receiver relations in a ground water mass transport system.

from the source. It is important to realize that the source is characterized by its strength, defined by the amount of contaminant released into the groundwater flow system per unit time. The source strength may vary with time due to natural decay processes or through sporadic input and re-activation by infiltration events. It depends on the mass transfer characteristics and solubility between the contaminant and the groundwater and the contact area across which the exchange reactions take place.

The internal contact area and the shape of the contaminant body are strongly determined by: (1) the conditions under which the contaminant is introduced into the subsurface; (2) the aquifer properties; and (3) the subsequent history of infiltration-recharge events. Artificial stresses such as pumping in the vicinity of the source also influence its shape.

It is further determined by the degree of solubility between the contaminant and the groundwater. Highly soluble materials such as road salts or entirely miscible liquids such as alcohol or phenols result in single phase flow and miscible displacement.

Very sparingly soluble materials such as creosote oils, tar products, and other hydrophobic hydrocarbons form separate fluid phase regions. They are severely restricted in their mobility by capillary forces and interfacial phenomena. The

persistence of a source depends on its initial volume, replenishment rate, if any, and dissolution or decay rates.

Because of its low mobility as the non-wetting phase, and the low solubility of hydrocarbons and higher boiling coal tar derivatives, these substances constitute sources persisting over very long periods of time.

2.510 Contaminants in Urbanized Areas.

The purpose of this section is to enumerate the types of contaminants that generally are expected in an area of intermediate to high degree of urbanization including some industrial land use. From this discussion, those contaminants that are specifically linked to a particular source can be separated for further consideration.

Pollutants in the soils, subsurface and groundwater under urbanized areas are either directly linked to well defined activities or are the result of accidental releases. Examples of the first group are: dissolved salts from road salting which move downwards with infiltration; nutrients such as nitrogen and phosphorous in excess of biological demands due to overfertilization; high phosphorous in storm runoff from streets with leaves and organic debris, especially in the fall; nutrients and surfactants from septic tank operations; diverse chemicals from slowly seeping holding and storage ponds; and sulfur compounds as soil reaction products where



acid rain is precipitated from the atmosphere. Accidental sources of contamination are surface spills from leaks, tank rupture or vehicle accidents of almost any type of industrial chemical, but especially from failing underground storage tanks. Inappropriate and widespread disposal of small amounts of chemicals, most often solvents and cleaning fluids further contributes to the problem.

Because of the ubiquity of many compounds it is difficult to trace them back to their sources.

However, because of their very special origin coal-tar distillation derivatives can usually be traced with much more confidence on the basis of distinct patterns in the typical gas chromatographs.

- 3.220 Coal Tar Derivatives in the St. Louis Park Area. Most of the contaminants found on the Reilly Tar and Chemical site are coal tar derivatives such as phenolics and PAH's. This is to be expected from the past land use of the site as a coal tar distillation plant and wood treatment facility. It is, therefore, necessary to identify the nature of the organic compounds contained in coal tar and especially in creosote, and to discuss the former plant operations in order to define possible sources of contaminants and their geographical location.

#### 4.0.0.0 Distribution of Groundwater Contaminants

##### 4.1.0.0 Introduction

Determination of the method of introduction and distribution of groundwater contaminants is based on a large amount of chemical and hydrogeologic data. Groundwater data has been obtained from the analyses of water samples from production and monitoring wells in the site area. This data includes a broad range of chemicals; both inorganic and organic. Some of these groundwater constituents pose no health risk to humans, but are quantified for use as tracers of groundwater flow or indicators of anthropogenic activity on the groundwater system. The groundwater chemicals of health concern which are attributable to the former Reilly operations are phenolics (compounds with one benzene ring) and PAH (compounds with 2 or more benzene rings).

Hydrogeologic data must be coupled with the water quality data to provide the explanation for the introduction and movement of contaminants in the groundwater system.

Pertinent hydrogeologic data includes stratigraphic logs of wells and soil borings, well construction data, water level measurements, water use data, microbiological activity investigations and field and laboratory hydraulic testing. These types of data have been obtained from the site area in a number of data collection efforts and

studies by contractors to state and federal agencies and to Reilly Tar and Chemical Corporation.

Two comprehensive studies which present basic chemical and hydrogeologic data, and its interpretation to assess the groundwater problems, have been conducted by Hult and Schoenberg (1981) and Hult (1984) at the U.S. Geological Survey, St. Paul District. The following discussion of groundwater contamination due to the former Reilly operations draws on all available information, but is best substantiated by these two studies.

#### 4.2.0.0 Glacial Drift Aquifer

The glacial drift consists of all unconsolidated deposits above the bedrock layers. As previously mentioned, introduction of coal-tar derivative contaminants to the glacial deposits has occurred on-site due to product drippings, leaks and spills, and off-site in the adjacent southern swamp area which received the plant's wastewater effluent. Glacial soil and groundwater contamination could occur due to seepage of liquid from the wastewater ditch and swamp area.

Contained within the glacial drift is the Drift aquifer which consists predominantly of sand and gravel. The groundwater flow direction is generally southeast or east from the site in this aquifer. Therefore, the input of contaminated

seepage from the swamp area, or of contaminated infiltration at the site, results in Drift aquifer groundwater quality degradation east and southeast of the site. The greatest impact on water quality in the Drift aquifer is found in the swamp area at well W13. This well produces a dark colored fluid which, at rest in a container, separates into two phases. This indicates the presence of a highly concentrated mass of contaminants in the aquifer which can cause very long-term contamination as it dissolves into the more mobile groundwater flowing past.

The most intensely monitored area of the Drift aquifer is along the groundwater flow path through the swamp and to the southeast. Water quality and water level data indicate that groundwater containing PAH is present above an exposure of the St. Peter aquifer ( which is normally protected by the overlying Glenwood shale) in a bedrock valley along this flow path. At the bedrock valley, the potential exists for downward flow from the Drift to the St. Peter aquifer. This could result in the introduction of significant amounts of PAH to the St. Peter.

#### 4.3.0.0 Platteville Aquifer.

The Platteville aquifer is present below the Drift aquifer throughout the area of Drift contamination except in the area of the bedrock valley southeast of the site. The basal drift

separates the Drift and Platteville and acts as an aquitard, impeding downward flow. This aquitard is relatively conductive, however, in comparison to the bedrock aquitards. The basal drift has allowed leakage of contaminated groundwater from the Drift to the Platteville due to higher water levels in the Drift than in the Platteville. The potential for downward flow was greatest in the swamp area where waste water discharge from the former plant produced elevated groundwater levels or mounding in the Drift.

The ground water flow direction in the Platteville is similar to that of the Drift aquifer. The observed area of groundwater quality degradation is, as a result, similar to that of the Drift with the principal source of contamination being downward flow in the swamp vicinity. PAH and phenolics concentrations observed in the Platteville are typically lower than those of the Drift due to the diluting process which occurs as contaminated groundwater slowly leaks downward from the Drift to the Platteville.

The Platteville is, and has been used as a lower-capacity source of commercial and industrial water supply. This water use from low-capacity wells in or near the area of contamination would be expected to locally affect ground water flow directions and flow velocities and would withdraw contaminated ground water. Such withdrawals have not, however, captured all contaminated groundwater in the Platteville.

#### 4.4.0.0 St. Peter Aquifer.

The Glenwood shale is a thin layer of very low hydraulic conductivity which separates the St. Peter and Platteville aquifers throughout most of the site area. This layer significantly impedes the downward flow of contaminated water from the Platteville to the St. Peter. However, this layer is missing in the bedrock valley area southeast of the site and has been penetrated in on-site and off-site multiaquifer wells which connected the Platteville and St. Peter aquifers.

As stated in the previous Glacial Drift discussion, the St. Peter is most susceptible to downward leakage of contaminated groundwater in the area of the bedrock valley. The Drift and St. Peter are separated by the basal drift (an aquitard) in the valley, but this layer is not as effective as the Glenwood shale for resistance to downward flow. Multi-aquifer wells connecting the Platteville and St. Peter in the area of Platteville contamination may also be a source of contaminants to the St. Peter. A phenomenon of these wells by which the bore hole wall is impermeabilized, termed "skin-effect," may significantly reduce the amount of contaminant input to the St. Peter by such wells. Multiaquifer wells may exist, or have existence, at various points dispersed over the area.

The effects of multiaquifer wells and leakage in the bedrock valley are expected to result in a contaminant distribution with a multiple source area. Movement of contaminants which may be introduced by these sources would generally be southeastward in the natural direction of groundwater flow. This flow pattern will be locally altered by production wells.

#### 4.5.0.0 Prairie du Chien - Jordan Aquifer

The Prairie du Chien - Jordan aquifer is normally protected from surface activities in the site area by the overlying aquifers and aquitards. The principal source of PAH to the aquifer has been multiaquifer wells; in particular one on-site well, W23. The open-hole (i.e., uncased or unscreened) bore of W23 was found to contain a plug of coal-tar derivative materials starting at a depth below the Jordan sandstone. Above this plug, the well bore was heavily contaminated with similar materials. The dissolving of PAH from this material and downward flow of water in the well bore produced significant contamination in the aquifer over many years.

The natural groundwater flow direction in the Prairie du Chien - Jordan is southeast to east from the site, with discharge to the Mississippi and Minnesota Rivers. This flow

pattern is greatly altered, however, by the many high capacity municipal and industrial wells which tap the aquifer. As a result of prolific use and the flow properties of the Prairie du Chien, contaminants introduced to the Prairie du Chien - Jordan have traveled in all directions from the site, with an area of groundwater degradation much larger than those of the overlying aquifers. In response to this contaminant migration, six St. Louis Park and one Hopkins municipal supply wells have been closed. Nonpotable use, industrial supply wells in the area of contamination have not been closed and have played a significant role in distorting the plume and removing PAH from the aquifer.

#### 4.6.0.0 Ironton - Galesville Aquifer

The Ironton - Galesville aquifer, like the Prairie du Chien - Jordan, has been contaminated with PAH due to multiaquifer wells. Wells which potentially introduced contaminants to this aquifer in the St. Louis Park area are the two on-site wells, W23 and W105, and the former Milwaukee Railroad well southeast of the site (W38, near Old St. Louis Park #1). These wells were known to be drilled into the Mt. Simon - Hinckley aquifer in original construction, with the Ironton - Galesville and one or more of the overlying aquifers open to the well bore. Samples from these wells have all indicated the presence of PAH, and the well construction provided a



hydraulic opportunity for inflow to the Ironton - Galesville.

The Ironton - Galesville is not locally used for water supply. Because so few wells are completed in this aquifer distribution of contaminants and flow direction in the aquifer are not well known in the St. Louis Park area.

#### 4.7.0.0 Mount Simon - Hinckley Aquifer

Being the deepest aquifer in the geologic sequence at St. Louis Park, the Mt. Simon - Hinckley is best protected from surface activities. However, the presence of multiaquifer wells W105, W23, and W38 could have allowed the introduction of PAH to this aquifer under similar conditions to those stated above in the Ironton - Galesville discussion. One factor which would lessen the potential for Mt. Simon - Hinckley contamination due to these wells is that their open-hole construction allows sluffing and filling of geologic materials (mostly sand) into the well from formations open to the well. After settling to the bottom of the well these materials obstruct the potential inflow of contaminated water to the Mt. Simon - Hinckley.

Unlike the Ironton-Galesville, the Mt. Simon - Hinckley is used locally as a source of municipal water supply. The effects of high-capacity pumping wells dominate the direction of flow in the aquifer. The nearest municipal wells are those of St. Louis Park (i.e., numbers 11, 12, 13 and 17).

If contamination has occurred due to the multiaquifer wells, the contaminants would be expected to travel to one or more of these municipal wells. The travel time to any of the wells depends on the source behavior of the multiaquifer wells, the pumping of each municipal well, aquifer characteristics and possible absorption effects. Movement of contaminants in this aquifer would be much slower than that of the Prairie du Chien - Jordan because of textural and hydraulic property differences. None of the Mt. Simon - Hinckley municipal wells indicate contamination by PAH.

#### 5.0.0.0 Remedial Actions

##### 5.1.0.0 Introduction

Available remedial actions may be broadly categorized as source control, gradient control or point of use control. Source control remedial actions would be employed to minimize or eliminate the input of contaminants to the environment. For example, a source control remedy would prevent contaminants already present in the soil from entering groundwater by removal of all contaminated soil.

Gradient control is directed at modifying the flow field to control contaminants already moving through an aquifer. Point of use controls would be implemented to remove or reduce the impact of the contaminated natural resource at the point of use. An example of a point of use control is treatment of a water supply at a drinking water well.

The following recommended or anticipated remedial actions for the site and affected area are grouped into these three categories. Selection of one of the remedial measure components will usually influence the effectiveness or reliability of the other remedial components in the system (e.g., source control may make discharge without treatment possible for gradient control wells in an aquifer). Therefore, remedial measures directed toward an aquifer system must be evaluated as a whole, rather than individually as a source, gradient, or point of use control.

#### 5.2.0.0 Source Controls

##### 5.2.1.0 Separate Phase Coal Tar Derivatives

A considerable amount of separate phase coal tar derivative material is present in the subsurface environment due to the former site operations. The locations of such materials include (1) the near-surface soils underlying the site area which were subject to spills, leaks and drippings; (2) the near-surface soils along the route of the former waste water ditch and in the swamp area into which the ditch discharged; (3) the vicinity of well W13 in the Drift aquifer near the swamp; and (4) within the pore spaces of the Prairie du Chien formation in the vicinity of well W23. Very small amounts of these materials have the potential to contaminate large volumes of water, considering that the separate phase material is composed of a high percentage of PAH and that water is contaminated at very low concentrations of PAH (parts per trillion level for carcinogenic PAH).

The remedial measures implemented to control the mobility of these highly concentrated source materials depend on the location of the source. For the near surface contamination, minimum remedial measures would include (1) determining the extent of such materials through a shallow drilling investigation, (2) reducing the infiltration of water through the contaminated soils by capping the area with low conductivity material, and (3) grading the surface to promote runoff away

from the site and prevent infiltration. A more ambitious, and much more expensive, remedial measure is the removal and treatment or disposal of the separate phase materials and surrounding soils.

Remedial measures directed toward control of the separate phase materials in the Prairie du Chien near W23 and in the Drift aquifer near W13 may be desirable or necessary in conjunction with other remedial actions considered for the aquifers. One proven method of source control which is a viable option for these two aquifers is to pump wells W13 and W23 each at a low rate (less than 100 gpm) designed to capture groundwater which contacts the separate phase materials near the wells.

#### 5.2.2.0 Multiaquifer Wells

Due to natural water level differences between aquifers in the St. Louis Park area, wells open to two aquifers have the potential to allow flow from the upper aquifer into the lower aquifer. When the upper aquifer open to such a well is contaminated, the well can act as a contaminant source to the lower aquifer. On-site wells W105 and W23 and other wells in the vicinity of the site were multi-aquifer wells that have been rehabilitated in recent years. At least eight other wells are known, or suspected, to be multi-aquifer wells which may act as continuing sources of contamination to lower aquifers. These wells warrant investigation and possible reconstruction or abandonment.

A form of source control can be implemented with a multi-aquifer by reconstructing the well to produce water from an aquifer which formerly received contaminated inflow. Well W23 has been reconstructed as a Prairie du Chien - Jordan well and W105 has been reconstructed as an Ironton - Galesville well. Pumping these two wells is a possible remedial measures for source control in the two aquifers.

#### 5.3.0.0 Gradient Control

Gradient control consists of pumping ground water at specified rates and locations within an aquifer so as to control the direction of ground water flow. The intention of such a system is to confine the spread of contaminants and to capture and withdraw some of the contaminated ground water; thus, the remaining aquifer areas outside of the area of influence of the gradient control system are protected.

Gradient control is typically implemented in aquifers in which the spread of contaminants has progressed to the stage where containment using only a source control technique is no longer feasible. The areal distributions of contaminants in the Prairie du Chien - Jordan, Drift and Platteville aquifers have been observed to be large enough in extent to make gradient control the prime remedy for recovery or control of the contaminants.

To design an effective gradient control system for an aquifer, the area of contamination must first be fully defined. Existing data is inadequate to define fully the area of contamination for the Drift, Platteville and St. Peter aquifers. A drilling and sampling program in these aquifers is, therefore, necessary before gradient control systems can be designed.

#### 5.4.0.0 Point of Use Controls

Point of use controls are remedial measures which treat or control contaminated groundwater for human consumption, industrial, agricultural or other uses at the point the contaminated water is withdrawn. This control may take the form of a well prohibition or advisory, in which case groundwater withdrawn from a specified aquifer area may not be used, may be used only for certain purposes (e.g., industrial or cooling water), or may be used only after treatment. Such restrictions in use and discharge will change as changes in the distribution of contaminants in each aquifer occur over time.

One point of use control, or remedial action, necessary to restore the City of St. Louis Park's water supply capacity, is the construction of a granular activated carbon treatment plant for use at municipal wells 15 and 10. These wells are closed Prairie du Chien - Jordan aquifer wells. A feasibility study and design testing for this plant have been completed.

#### 5.5.0.0 Contingencies and Monitoring

Remedial measure design necessitates approximating actual, complex field conditions with simplified design models. As a result, the inaccuracies inherent in the design models or conditions which were not observed at the time of design may cause failure of the implemented remedy to produce the desired effect. It is, therefore, necessary to design a monitoring system capable of assessing remedial action effectiveness and to plan contingent remedial measures.

Contingent actions could include, for example, abandonment of newly discovered multiaquifer wells, contingent drinking water treatment at a municipal well or the addition of gradient control wells. Monitoring of remedial measure effectiveness will include acquisition of water level measurements for flow direction determination; water quality sampling to determine contaminant distributions, treatment system performance, or compliance with discharge permits; and water use tracking within the St. Louis Park area. These data will require interpretation by a professional staff qualified to make any necessary changes to the original remedial action plan.